Improving Solar Gain Control Strategies in Residential Buildings Located in a Hot Climate (Tripoli-Libya)

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Abstract

A large number of recently-built residential buildings in Libya provide a poor quality indoor environment or require a huge amount of energy to run the air conditioning, therefore influencing the thermal comfort, energy consumption and carbon emissions. As the use of energy in buildings is the major contributor to air pollution and global climate change, improving energy efficiency through the application of bioclimatic design principles in residential buildings in Libya is a critical factor in reducing energy consumption, securing thermal comfort, and hence is an effective policy for reducing the environmental impacts such as global warming and ozone layer depletion.

This research assumes that the use of appropriate orientation, materials and building configuration would offer suitable solutions for energy and environmental problems in hot, arid countries. This hypothesis is examined through an example located in Libya. A domestic building in Libya was studied with a view to reducing its energy consumption. The study included detailed monitoring for 45 days continuously, followed by computer simulation of a range of intervention strategies.

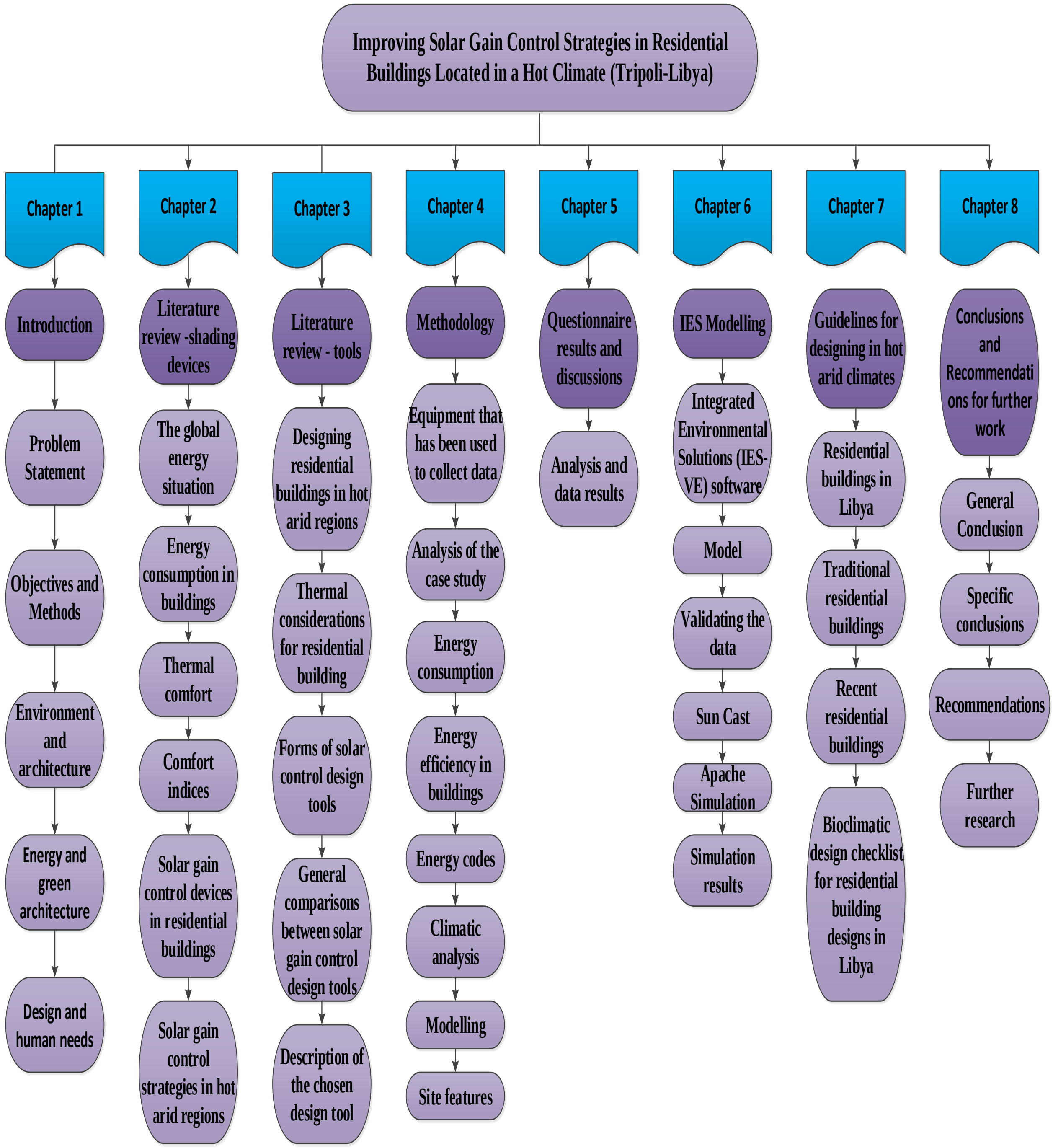
A field study including temperature, humidity and electricity consumption measurements was carried out and results from the study were gathered and analysed. Moreover a computer simulation model was built using IES software, a fully dynamic simulation model to investigate the potential influence of changes to the building.

The thermal comfort of users in a residential building in Tripoli, Libya was investigated. Field measurements and subjective environmental perception survey were used. It was established that building design in hot arid regions must consider thermal requirements.

Keywords:

Poor indoor quality; Building orientation; Building energy control and consumption; energy saving in a buildings.

The Thesis Structure and Sequence



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IN THE NAME OF ALLH THE MOST GRACIOUS, THE MOST MERCIFUL

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Last but not least, I would like to dedicate this work to my eldest brother, the deceased ***Dr. Mohammed Fathi El Bakkush.***

ACADEMIC REGISTRY

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Published Papers

The following papers have been published as a result of this research:

El Bakkush, A.F; Lasker, W.J; Harris, D.J. (2015) '**On-site measurements of thermal performance of a residence building in hot-arid region**' *International Journal for Housing Science and its Applications, Vol. 39 Issue (3) October.*

El Bakkush, A.F; Bondinuba, F.K; Harris, D.J. (2015) '**Exploring the Energy Consumption Dimensions of a Residential Building in Tripoli, Libya**' *International Journal of Engineering Research & Technology (IJERT), Vol. 4 Issue 10, October.*

El Bakkush, A.F; Bondinuba, F.K; Harris, D.J. (2015) '**The Effect of Outdoor Air Temperature on the Thermal Performance of a Residential Building**' *Journal of Multidisciplinary Engineering Science and Technology (JMEST), Vol. 2 Issue 9, September.*

El Bakkush, A.F; Bondinuba, F.K; Harris, D.J. (2015) '**The Application of Building Modifications and their Effects on Energy Consumption in Buildings**' *Journal of Energy Technologies and Policy (IISTE), Vol.5, No.8.*

El Bakkush, A. F; Harris, D. J. '**Thermal Performance Measurements of a Residential Building Located in Hot Arid Area (Tripoli-Libya)**' *Proceedings of conference: The 7th International Conference of SuDBE2015, Reading, UK; 27-29 July, 2015.*

El Bakkush, A. F; Harris, D. J. '**Improving Solar Gain Control Design Strategies in Residential Building Located in Hot Arid Areas'** *Proceedings of conference: The London-Loughborough (LoLo), Sustainability and Buildings Walking the tightrope to 2050, Loughborough,UK; 22nd April 2015.*

In press under review

El Bakkush, A. F; Harris, D. J. '**Electricity consumption and its relation to temperature residential building'.**

1 Chapter 1: General introduction

1.1 Introduction

Buildings, in addition to offering shelter and fulfilling aesthetic needs, should provide conditions of comfort for their occupants. During summer, especially in hot climate regions, buildings are exposed to high intensities of solar gains, which may result in over-heating conditions that cause discomfort to the users. Under these conditions, cooling the building is very important. Cooling is used in order to achieve a lower temperature and/or humidity level than those of the natural surroundings. Cooling processes can include diverse measures starting from simple natural cooling techniques such as solar gain control, evaporative cooling and natural ventilation, to mechanical cooling systems known as air conditioners (Santamouris & Asimakopolous, 1996).

In the earliest cooling system technology attempted, people managed to keep cool using natural methods, such as breezes flowing through windows, water evaporating from trees and fountains, as well as large amounts of stone and earth absorbing daytime heat. These ideas were developed over thousands of years as an integral part of all building designs, known as "passive cooling". By engaging passive cooling techniques in new buildings, however, the designer can often eliminate the need for mechanical cooling, or at least cut down the size and cost of the equipment. The two important principles in any passive cooling design are to eliminate unwanted heat gains and create cooling instead. In summer, various sources of heat gain have to be dealt with. These are from direct solar radiation outside and also internal gains from residents inside, such as lighting and other equipment, as shown in Figure1.1.

Figure 1.1 Traditional bioclimatic cross ventilation.

Designers have the obligation to use a range of techniques to eliminate the energy needed and increase the ability of buildings to create their own energy. The main principle of "green architecture" is energy efficiency over life cycle of a building.

1.2 Problem statement

As people's living standards rise, they want to improve thermal comfort in their homes by installing cooling equipment. For a building not adapted to the climate, the amount of energy to run the equipment and thus its cost will be excessively high, and it will also have an on-going negative impact on the environment. The majority of new residential buildings nowadays in Libya, particularly, are designed without any energy efficiency considerations beyond those enforced by the energy codes.

There are many reasons why environmental considerations are neglected by architects. Some may view them as having very prescriptive solutions that tend to restrict design creativity, while other architects regard them as 'peripheral issues' compared to planning or aesthetic considerations (Marsh & carruthers, 1995). But the main reason for disregarding environmental considerations in building design, especially solar control design, can be attributed to the lack of means to assess the impact of new methods reliably during the building design process. The majority of architects appear to recognize the importance of design tools for energy efficient buildings but lack sufficient time or knowledge to adequately employ them, because of the enormous range of design tools available (Ellis & Mathews, 2001). Once the products of environmental science and particularly solar control research are translated into a form which can be easily assimilated into the design process, architects are likely to begin to use them sufficiently early in their designs. In order to achieve this goal more research and studies need to be carried out in this field.

There is also the problem of the large amounts of energy required for cooling buildings in a hot sunny climate; reduction of solar gain in residential premises can not only improve comfort but also save costs in electrical cooling during the whole year. In fact, according to Datta (2001), almost 50% of cooling loads in non-residential premises and over half in residential buildings are due to solar gains (Datta, 2001). It has been estimated that the proper application of energy efficient solar control devices in new buildings has the potential to save 50-70% of electric lighting use and 50-60% of total perimeter zone energy use (Selkowitz & Lampert, 1989) as well as bringing about an improvement in comfort for residents of these types of buildings.

This study starts off with the hypotheses that most residential projects in the Tripoli region are problematic from the view point of passive thermal performance, especially solar gain control aspects at both the planning scale and the architectural scale.

1.3 Objectives and methods

The thesis has two main objectives. The first objective is to develop guidelines for solar control devices and strategies for residential buildings in hot, arid climates, in order to enhance human indoor comfort conditions, by using Tripoli as a case study city. The second objective is to provide the guidance needed by building designers in selecting the most appropriate tool for designing solar control devices in residential buildings by establishing sufficiently detailed conclusions on the accuracy of such design tools in the appropriate task.

The analysis of the indoor thermal comfort conditions of a residential building in a hot arid climate was carried out using Tripoli as a case study city (at the micro level) with the aid of a computer simulation program calibrated with field measurements from the case study buildings themselves.

The development of design guidelines and strategies for residential buildings in hot, arid regions was achieved using computer simulations to design the appropriate solar control strategy and devices.

The first task was to carry out a survey of an existing building. In this phase, information was collected about the outdoor climate from meteorological stations and about the indoor climate normally experienced by the population.

The second task was the computer modelling study, to establish the influence of each parameter, such as orientation, on the indoor climate and the occupants' thermal comfort. The objective in this stage was to find the best solution in terms of solar control devices.

The thesis will focus only on the solar control design of residential building in developing countries (Libya as an example) which generally have poor thermal and aesthetic design. Therefore, this study does not investigate the effects of major changes to the main configuration of the building in terms of building shape and size, as these are generally restricted to basic design.

1.4 The environment and architecture:

By upsetting the delicate web of the environment of which they are part, human beings will lose some of the values and benefits offered by nature. Nature is an interactive system where changes to any of its subsystems will affect the operation of whole, and if one of its components stops functioning, the whole system may collapse. Hence "one must touch this lightly," as quoted by the Australian architect Glenn Murcutt.

Modern buildings represent an extra ordinary achievement that has made our lives easier but with a hidden cost throughout the whole life cycle of the building. Le-Corbusier summed up the conventional twentieth century vision of building when he called the house "a machine for living". He also proclaimed in 1937 "I propose one single building for all nations and climates" (Roodman & Lenssen, 1995). Modern buildings thus became divorced from their surroundings, thus causing dramatic damage to the environment. This century is potentially one of the most challenging periods of architectural innovation in history because of the urgency and increasing expansion of the environmental movement. Architecture is now in an evolutionary stage towards a new relation with nature. This is because it is perceived that architecture has become a part of the environmental problems rather than being a solution. It has been targeted as one of the most culpable of the environmental enemies.

The science of ecology has provided a radically expanded view of the environment and has also laid the foundation for a new architectural iconography. Awareness of the environmental issues is treated as if it is a new development, yet ecologists have been involved with these issues for many years: the problem was that people were not listening. In ancient and vernacular architecture, we can see some clear ecological standards which provide instructive examples of how to deal with climate and demonstrate ideas and approaches leading to low-tech solutions that can be incorporated into contemporary buildings. Most importantly these cultures offer the basis for rethinking our relation to the earth. The major scientific discoveries of the 16th to the 18th centuries, led western societies to believe that nature could be conquered through science, resulting in a reliance on techno-centrism (Wines, 2000).

The strongest voice of resistance was Frank Lloyd Wright: as early as 1910, before the word "ecology" was in common use, he was the pioneering force behind "organic architecture". In 1960 the concept of "environmental design" became fashionable. It was defined by Maurice Jay as "the scientific design and control of the man-made environment" (Walker, 1992). Furthermore, in 1962 Rachel Carsons book "Silent Spring" brought environmental problems to the attention of the public as one of the motivating alarm signals for the environmental youth movement that followed (Wines, 2000). In the 1970s ecology, popularly described as a new science, became involved in all fields of life, (Vale & Vale, 2000). "Ecological architecture" emerged in response to the problems of expensive fuels and world energy resources. After the earth summit conference in 1992 in Rio de Janeiro, Brazil, which was aimed at promoting sustainable development, there was a shift towards sustainable architecture.

Following this shift, "green architecture" emerged and nowadays we can even hear about the "cosmological architecture" which regards the building in terms of our cosmology, the great container of all of us. This leads to define a notion of holistic architectural design.

1.5 Energy and green architecture

Most of the world's activities depend on energy consumption; hence, energy is the key problem to be considered if humanity is to continue living on earth. The energy sources are divided into two categories non-renewable (finite) and renewable. The non-renewable energy sources are those that are no longer being made naturally. They include fossil fuels (coal, oil, natural gas) and minerals such as uranium. The renewable energy sources are those that are derived from natural resources and are regenerative and cannot be depleted. They include solar energy, wind power, geothermal energy, biofuel, and water power (Vale & Vale, 1991).

The consumption of fossil fuels is one of the biggest environmental problems. Fossil fuels, which are non-renewable energy sources, supply much of the energy used worldwide. Air pollution and the destruction of the atmosphere all result from the incredible demand for these fuels (Wines, 2000). Buildings mainly depend on them; thus energy use, as a parameter in green architecture, should be carefully considered and the importance of the use of clean and/or renewable energy resources should be appreciated.

1.6 Design and human needs

If we consider that buildings are habitats for people, then we can conclude that a successful building is one that serves the needs of the people living in it.

Humans have basic instincts to fulfil, both survival needs and well-being needs (Heerwagen, 2008). Their survival needs include air, water, food and shelter, while their well-being needs include factors that affect social and psychological health, such as acoustic levels .Thus the quality of building, the materials used, indoor air quality, use of day lighting and acoustic designs have a great impact on the performance of their users (Heerwagen, 2008). We spend most of our time indoors. Thus people, their health and well-being are important assets in architectural design. Architects are not building for machines but for humans to inhabit and their designs will ultimately impinge on the senses of those people who use them.

2 Chapter 2: Literature review- shading devices

2.1 Introduction

This chapter will present the energy consumption generally and for the Libyan regna specifically. The use of appropriate orientation, materials and building configuration would offer suitable solutions for energy and environmental problems in hot arid countries. This hypothesis is to be examined through an example located in Libya. A domestic building in Libya was studied with a view to reducing its energy consumption. The study included detailed monitoring, followed by computer simulation of a range of intervention strategies.

2.2 The global energy situation

The fossil fuels are being gradually depleted, and they cannot be replaced on any reasonable time scale of human civilizations. While the period of oil and gas might stretch out through the first half of this century, the shift to sustainable changes must happen earlier than physical or economic depletion of these valuable stored energy resources. Civilization must begin to take this transition seriously. According to British Petroleum, oil and natural gas will shortly be depleted. Oil is estimated to be depleted in 41 years while gas will be depleted in 67 years, and coal in 192 years (British Petroleum, 2004).

Most energy currently produced comes from burning fossil fuels which account for 90% of energy sources (El Bakkush, Bondinuba, & Harris, 2015). These non-renewable energy sources are finite, yet since 1950 global fossil fuel use has increased by 500 per cent Figure 2.1.

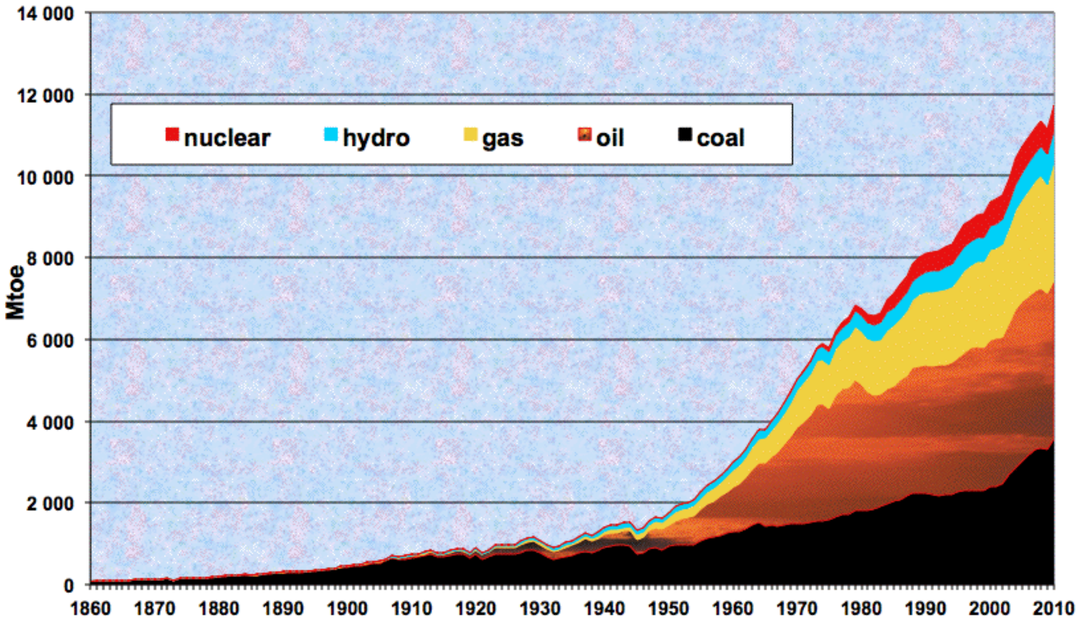

Figure 2.1 World commercial energy consumption (Manicore).

In Libya, the oil industry faces many challenges in the years to come. Oil output and production continues to decline due to technological problems and depletion of oil reserves.

A large number of recently-built residential buildings in Libya provide a poor quality indoor environment or require a huge amount of energy to run the air conditioning, therefore influencing the occupants' thermal comfort, as well as energy consumption and carbon emissions (Agency, 2011). As the use of energy in buildings is the major contributor to air pollution and global climate change, improving energy efficiency through the application of bioclimatic design principles in residential buildings in Libya is a critical factor in reducing energy consumption, securing thermal comfort, and hence is an effective policy for reducing the environmental impacts such a global warming and ozone layer depletion.

2.3 Energy consumption in buildings

Buildings are significant users of energy. The majority of the energy used in building is devoted to heating and cooling and lighting (Langston, 2001). The important drivers of growth in energy consumption associated with building have been identified as:

1. Population growth (which affect total consumption);
2. Poor residential building design;
3. Increased interest in use of energy using appliances in households to improve amenity; (Greene, 2004).

The energy consumption pattern in a building is affected by

1. Its design.
2. The environment in which it is located.
3. The way in which it is operated.

The estimation of the energy consumption of buildings has received significant attention in the past few years, with the dual goal of reducing energy cost (cost concerns), and reducing the amount of greenhouse gases released in the atmosphere (environmental concerns). Several methods and tools can be used to evaluate the energy consumption of the buildings, ranging from simple spread sheets to full simulation programs.

The design of energy for heating, cooling, and lighting in buildings is accomplished in three tiers. The first tier is the *architectural design* of the building itself to minimize heat loss in the winter, to minimize heat gain in the summer, and to use light efficiently. Poor decisions at this point can easily double or triple the size of the mechanical equipment and energy eventually needed. The second tier involves the use of *natural energy* through such methods as passive heating, cooling, and day lighting systems. The proper decisions at this point can greatly reduce the unresolved problems from the first tier. Tiers one and two are both accomplished by the architectural design of the building. Tier three consists of designing the *mechanical equipment* using mostly non-renewable energy sources to handle the loads that remain after tiers one and two have reduced the loads as much as possible (Lechner, 2001) The key factors influencing energy use in a building are shown in Figure 2.2.

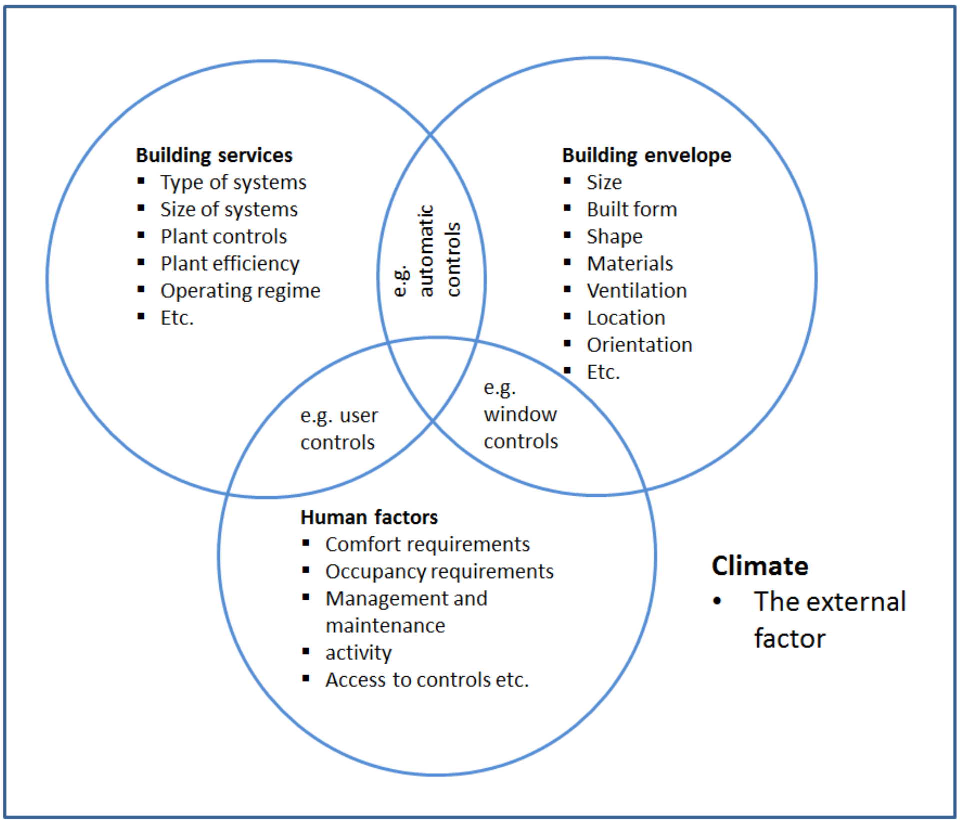

Figure 2.2 Key factors influencing energy use in buildings.

- **Building envelope**

The building envelope problem is the heat which escapes in winter through the building envelope or in counteracting the heat which penetrates the envelope in summer (Jarmul, 1980). Factors that affect this are location, orientation, size, built form, shape/layout, materials of construction, ventilation.

- **Building services**

Type and size of systems, type of energy, plant efficiency, plant control, operating regime, etc.

- **Human factors**

Comfort requirements, occupancy regime, human activity, management and maintenance, access to controls, etc.

Controlling energy used in buildings is central to any strategy to conserve fossil fuel supplies and reduce current global warming. In general, the building impacts upon energy consumption and global warming in four separate ways (Edwards, 1995).

1. The production of materials and products used to make a building;
2. The fabrication and construction process;
3. The heating, cooling, ventilation, and lighting of the buildings in use;
4. The infrastructure and transport cost of serving buildings.

The first three on this list are direct impacts, whilst the forth is indirect, though by no means insignificant. The effective strategy to succeed in minimising residential energy consumption must merge the following elements: product design and consumer education, planning regulation, energy sources, building standards and design.

2.3.1 A building as an energy system

A building may be described in several ways, concrete blocks, insulation, windows, and heating, cooling and ventilation systems. In addition, the energy system also includes the social context of the building, i.e. occupants of the building.

There are a number of issues influencing the thermal performance of a building, as shown Figure 2.3, the most observable is that it should give shelter and offer safety; but it must also supply energy for cooling, heating, ventilation, lighting and electrical appliances. Aesthetics and design are other significant factors that influence most of the aspects. Even the nearby trees and building influence the energy need of a building by shading, and the climate has to be engaged into account when calculating the annual energy need (Persson, 2006).

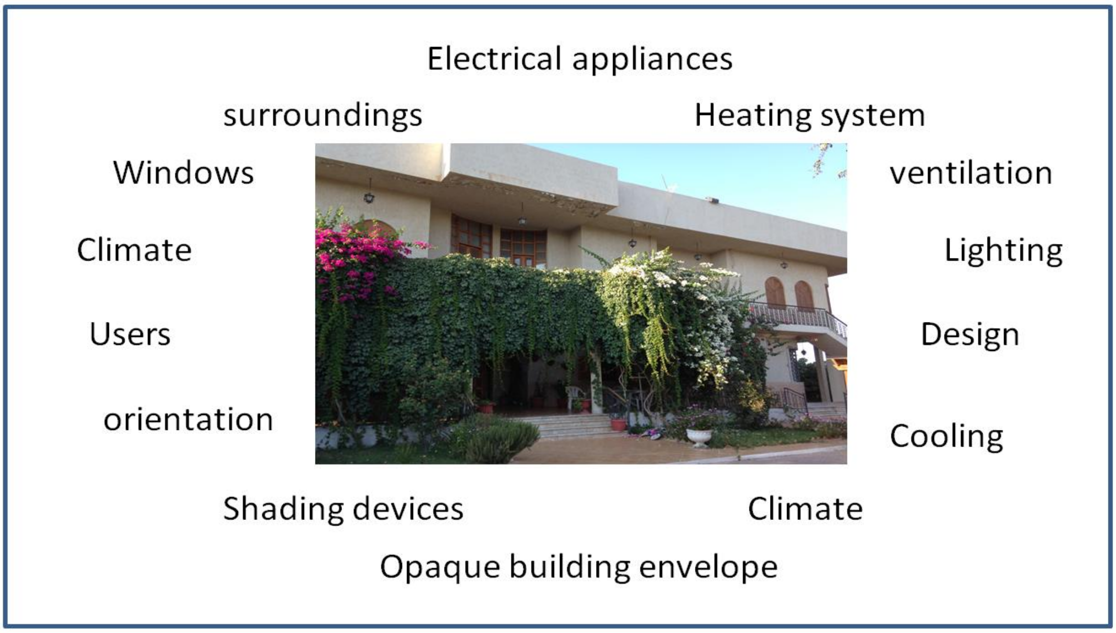

Figure 2.3 Different aspects which have an effect on the energy need.

2.3.2 Energy consumption in Libya

Libya's consumption of electrical energy is distributed into consumption by four major sectors: the industrial sector, the agricultural sector and the residential and commercial sectors as shown in Figure 2.4.

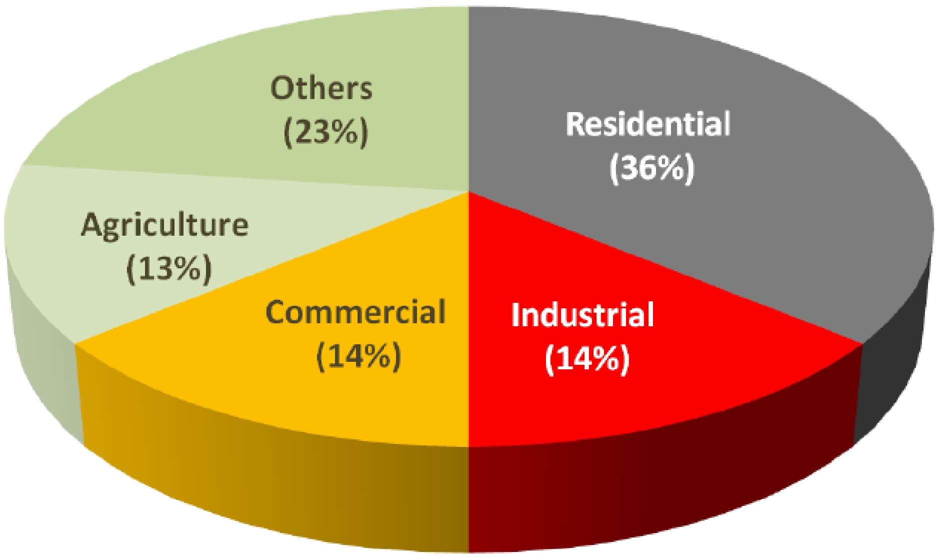

Figure 2.4 Electricity consumption per sector in Libya (GECOL, 2013).

40% of the total primary energy is used in power generation, and Figure 2.5 shows that 100% of the fuel used to generate power is fossil fuel and 0% renewables (GECOL, 2013). This means that the total CO_2 Emissions in Libya are around 60 million tonnes

CO_2 per year (55% due to oil and 45% due to natural gases) (GECOL, 2013) as shown in Figure 2.6.

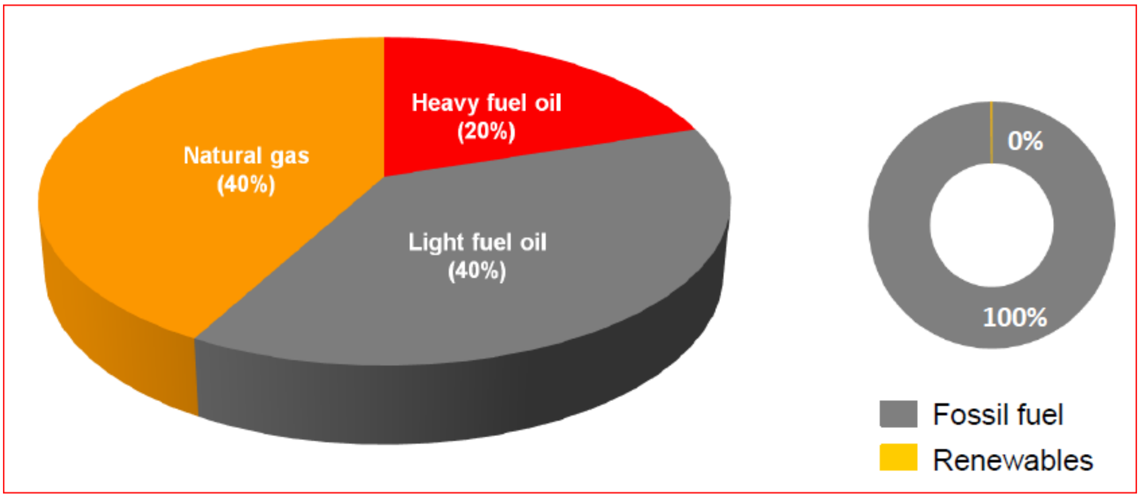

Figure 2.5 Electricity generation by fuel type (GECOL, 2013).

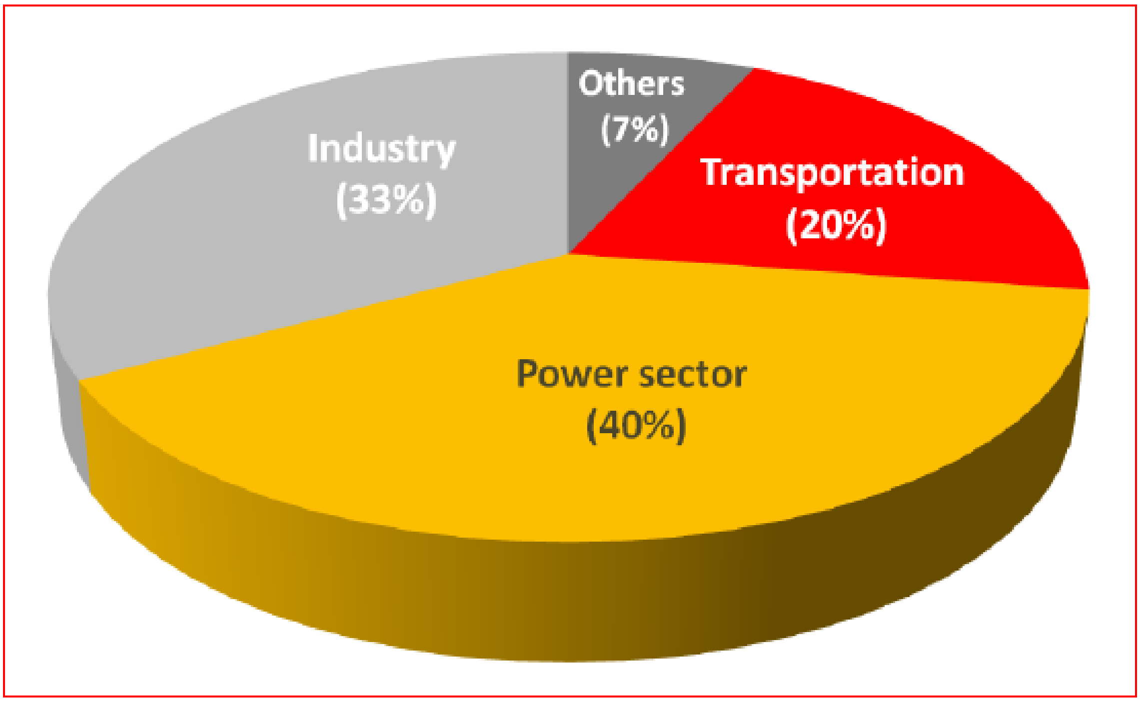

Figure 2.6 CO_2 Emissions in Libya (GECOL, 2013).

Moreover, energy consumption is on the increase year on year in Libya: Figure 2.7 shows the growth of electricity generation (2000-2010) (GECOL, 2013) amounted to more than 50% in the ten years between 2000 and 2001.

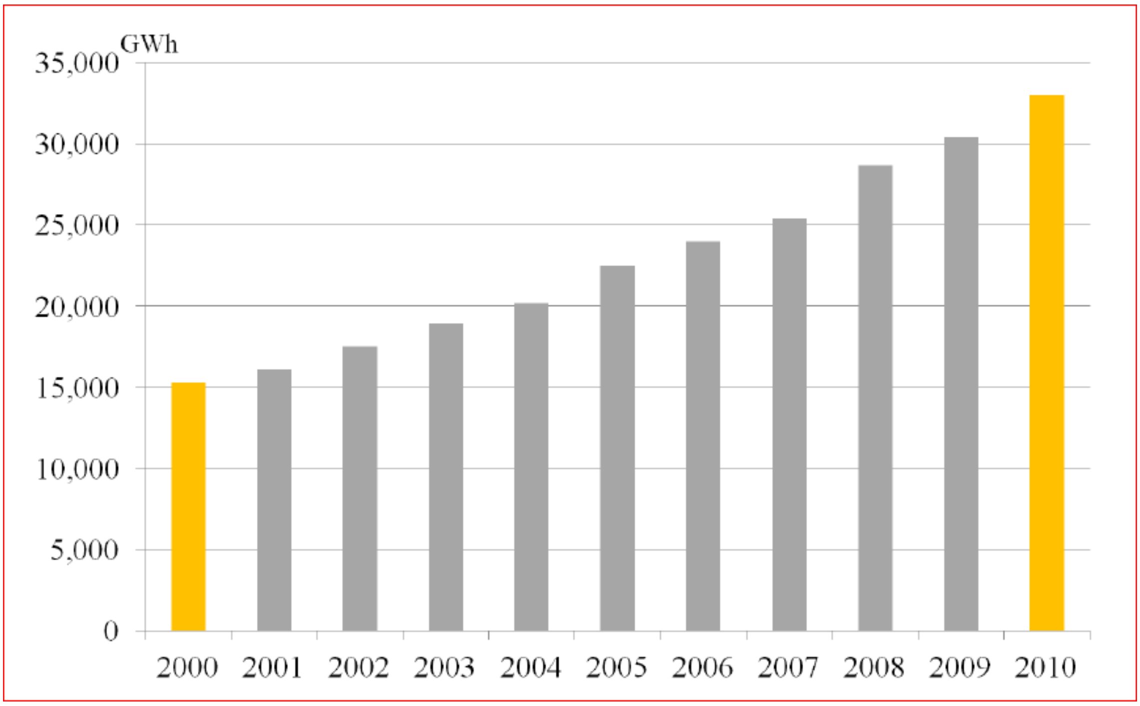

Figure 2.7 The growth of electricity generation (2000-2010) in Libya (GECOL, 2013).

A comparative study of electricity consumption per capita and electricity prices carried out by the Regional centre for Renewable Energy and Energy Efficiency (RCREEE), showed that electricity consumption per capita in Libya is 6 times that in Morocco, while the price per unit in Morocco is 5 times that in Libya, as can be seen in Figure 2.8.

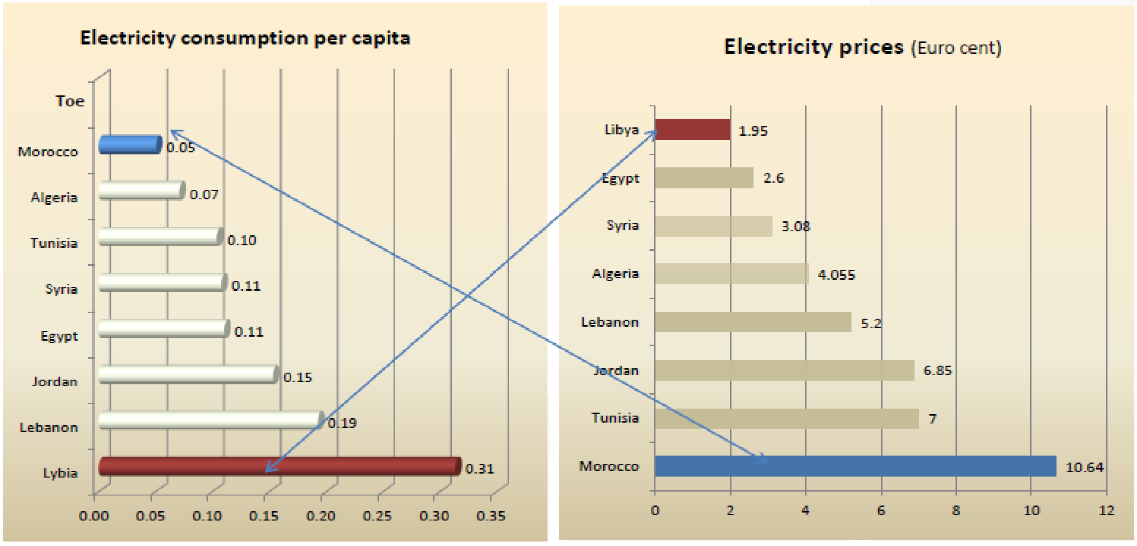

Figure 2.8 Comparison between electricity consumption and unit price (BIDA, 2013).

Another study (BIDA, 2013) shows the significant increase in electricity consumption in North African and Middle Eastern countries between 2003 and 2009 Figure 2.9, and it can be seen that Libyan consumption almost doubled in 6 years, which is an increasing cause for concern.

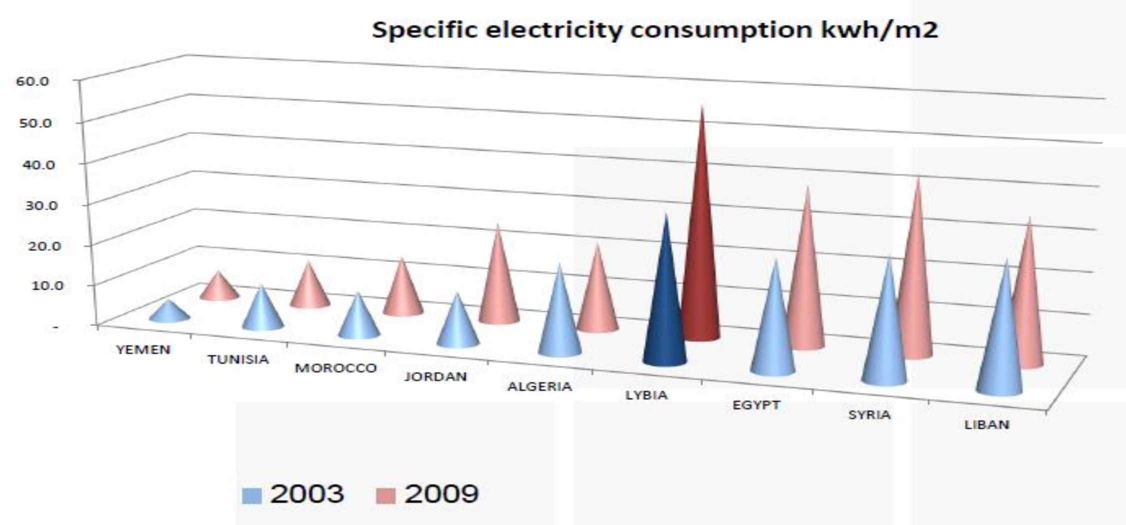

Figure 2.9 Specific electricity consumption kWh/m^2 (BIDA, 2013).

Although Libya is an oil producing country, there is an energy crisis in Libya for the following reasons:

Extensive use of conventional energy sources which are leading to their depletion, and the increase in the individual annual consumption of electrical energy, a significant proportion of which is due to consumption in buildings as pointed out above.

Most of the energy consumption is of non-renewable sources while the use of renewable sources is still in the foundation stages.

Inefficiency of electricity generation, which will lead to depletion of oil reserves in the near future.

It is well recognized a large percentage of all delivered energy consumption is accounted for by residential and industrial buildings where it is used for space cooling, water heating, lighting and appliances.

2.4 Thermal comfort

Comfort is an enormously complex criterion to design for. The human body has a special mechanism for producing heat. It requires surroundings that can allow it to live without thermal stress. Creating such conditions in buildings is a fundamental design objective, and can be achieved with minimum energy consumption. Passive cooling techniques (including solar gain control) should ensure the necessary indoor air quality needed for thermal comfort of the occupants. Some of the techniques used for passive cooling do not contribute in lowering the temperature but help by extending the tolerance limits for thermal comfort in a given space e.g. reducing humidity, increasing light (Santamouris, et al., 2001).

In his historical outline of architectural science, (Cowan , 1966) identified the principal problem of architectural science as “environmental design rather than structure”. However, 21 years later in, 1987 Manning wrote that although there had been a great deal of research into many aspects of the built environment, and an increase in knowledge, the design of the environment still frequently seemed to be “a matter of chance”. This chapter will first explain the concept thermal comfort for humans and then review the different attempts that have been made to establish ways to measure it. It will then look at the features of buildings and environmental design that can contribute to thermal comfort for the occupants as well as reducing energy consumption.

2.4.1 The occupant and thermal comfort

The important basis of thermal comfort is the way the temperature system in the hypothalamus of the brain works, such as monitoring the temperature changes in the blood caused by metabolic changes in the body and the internal temperature gradients through the skin. The system has a set point of 37.0°C, which it is trying to preserve. If the body temperature falls below this level, there will be a physiological response to raise the metabolic rate so that more heat will be generated; if the opposite happens the body begins to sweat and evaporate moisture from the skin to provide cooling. The extremes differ between sweating and shivering, altering the blood flow to the surface and controlling the body temperature. The objective of these responses is to maintain thermal equilibrium (Littler & Thomas, 1984).

The feeling of discomfort can happen when the internal temperature is unexpected or changes too quickly for adaptive measures to be efficient (Stack, Goulding, & Lewis, 1999).

2.4.2 Thermal sensation

Thermal comfort is a particular matter, which depends on a number of factors, such as the age, gender, culture, activity, clothing of the individual, and aspects of the internal environment such as air temperature, humidity, air movement, noise, light and odours

(O'Cofaigh, Owen, & Fitzgerald, 1999). The range of temperatures at which people feel comfortable is very wide: “it follows that each region of the world could adopt temperatures suitable to the prevailing climate and season” (Roaf & Hancock, 1992). Generally speaking, the human body can regulate its production of heat to the thermal conditions of the environment in order to feel at ease and experience minimum variations in the feeling of thermal comfort (Lewis, Goulding, & Steemers, 1992). This, designers aim to provide conditions that are acceptable to a majority of building users.

Human thermal comfort is defined as “the conditions in which a person would prefer neither warmer nor cooler surroundings” (ASHRAE, 1989). It can be defined as “a sense of well-being with respect to temperature”. One of the simplest definitions of thermal comfort is given by Givoni (1998) who explains that thermal comfort can be defined as the range of climatic conditions considered comfortable and acceptable to humans. This implies an absence of two basic sensations of discomfort: a thermal sensation of heat, and a sensation of skin wetness (Givoni, 1998), which depends on achieving a balance between the heat being produced by the body and the loss of heat to the surroundings. Research in the field shows that people are not passive in relation to their thermal environment; they look for comfortable conditions such as shade or sunshine, wind or shelter, and adjust themselves to feel more comfortable (O'Cofaigh, Owen, & Fitzgerald, 1999).

2.4.3 Thermal comfort zone

The range of conditions within which at least 80% of the people would feel comfortable, can be termed the “Comfort Zone” (Koenigsberger, Ingersoll, Mayhew, & Szokolay, 1974).

2.5 Comfort indices

Statistically, it is not possible to present a comprehensive list of every single one of the “comfort indices” from all categories, due to their variety. However, a comprehensive review and evaluation of major comfort indices is presented in (Givoni, 1998) as follows.

2.5.1 The ASHRAE temperature and comfort zone

The first effort at establishing comfort principles for use was initiated by ASHRAE between 1923 and 1925. This introduced the concept of Effective Temperature (ET) as shown in Figure 2.10, which is expressed as a single index for air temperature, humidity, and air speed. This guide puts forward the idea of using the skin as evidence and the interpreter of discomfort. (ET) is based on the percentage of the real evaporative loss at the skin surface to the maximum loss that might happen in the same environment, and at what time the skin is finally wet (ASHRAE, 1985).

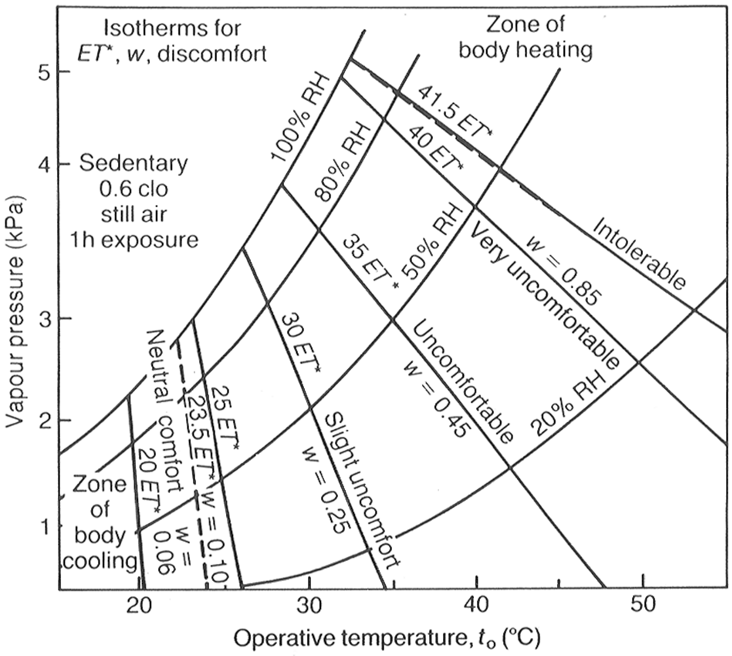

Figure 2.10 ASHRAE Effective temperature: Source, ASHRAE, 2001

This graph represents the neutral comfort region at 23.5°C dry-bulb temperature, with 50% humidity, and skin moisture of 0.06 (no sweating). Although this graph was uncomplicated and straightforward to use, it had a restriction on the types of clothes assumed to be worm (light clothing only).

Later, the ASHRAE developed further comfort index where the comfort zone is drawn on a conformist psychrometric graph, as shown in Figure 2.11, which indicates limitations of air temperature and moisture for inactive people (Givoni, 1992).

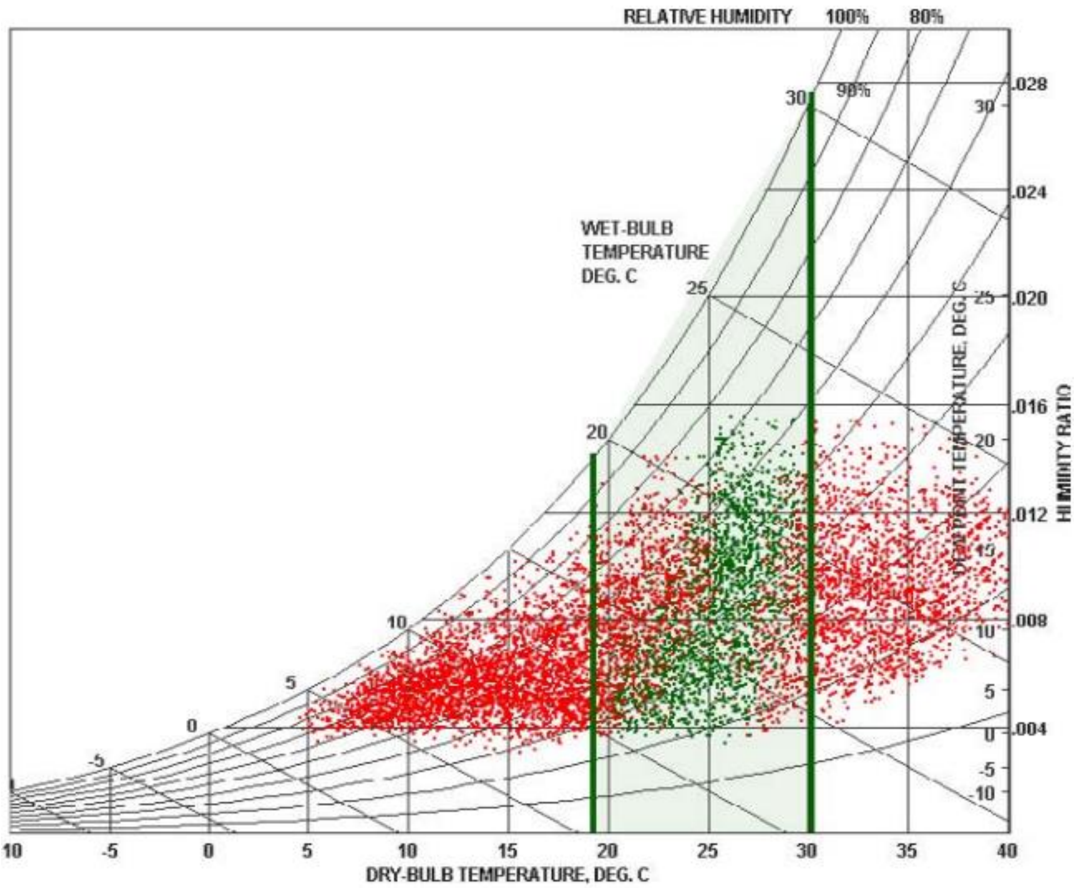

Figure 2.11 Comfort zone according to ASHRAE

2.5.2 Olgyay's Bio-Climatic chart

In 1963 Olgyay brought out his Bio-Climatic Chart, as shown in Figure 2.12. At that time it was the primary graphic comfort index available (Zuhairy & Sayigh, 1993).

The comfort range is presented in an XY plot of temperature (Y-axis) and relative humidity (X-axis). This comfort guide was planned to apply to non-conditioned buildings during natural ventilation; furthermore, it proposes that the summer comfort range might be shifted to a higher temperature and relative humidity as wind speeds rise. Olgyay's comfort graph was later subjected to an extra study by Givoni, who concluded that Olgyay's Bioclimatic was only successful for small buildings in moist areas, since it assumed an inside temperature very close to the outside (Givoni, 1976).

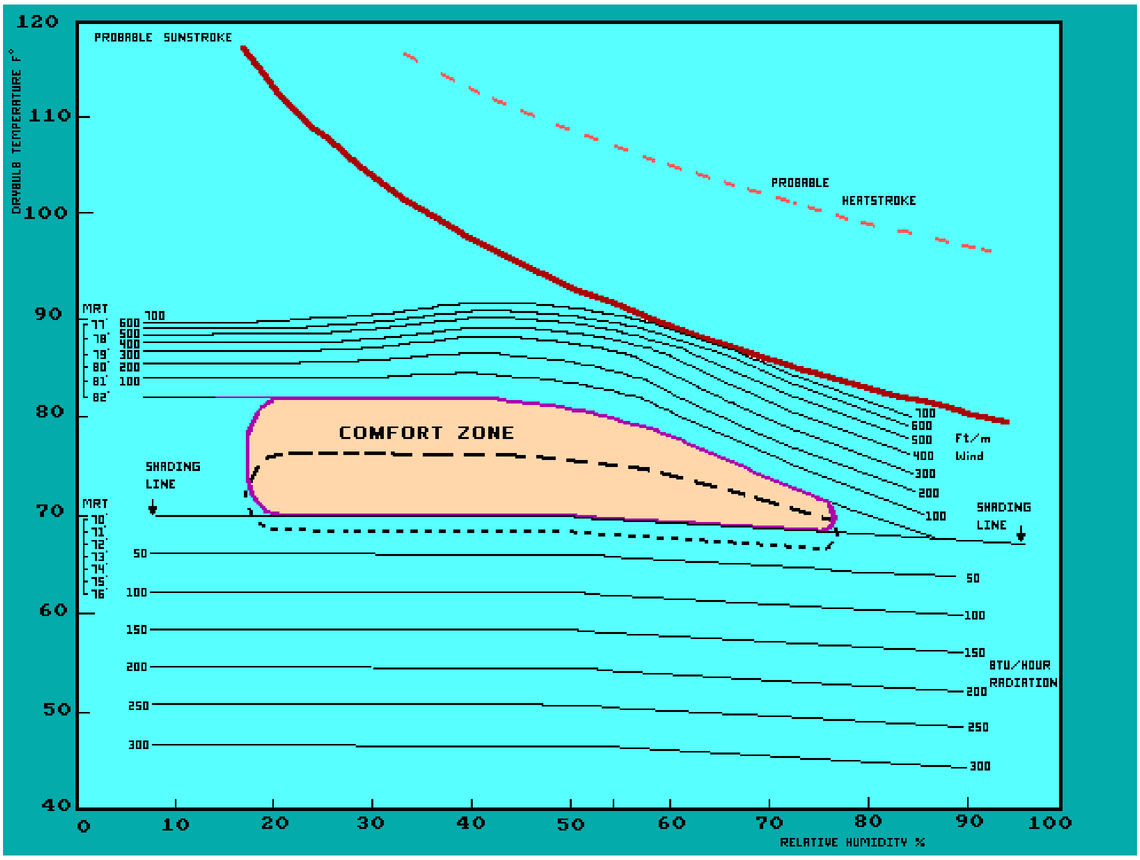

Figure 2.12 Olgyay's Bio-Climatic graph

2.5.3 Givoni's Building Bio-Climatic Chart (BBCC)

In view of the fact that Olgyay's chart supposed an indoor temperature extremely close to the outdoor one; Givoni produced an improved chart, the BBCC in 1976. Furthermore, in place of using outside temperatures to create the comfort index, as in Olgyay's chart, shown in Figure 2.13, he approximated the inside temperatures that would be affected by various factors, including hours of daytime ventilation, evaporative cooling, and thermal mass. The BBCC also suggests how passive cooling might afford inside comfort in hot weather with no use of air conditioning (Givoni, 1998): the BBCC indexes allow a stipulation at high relative humidity and temperature inside to be comfortable if the building uses natural ventilation.

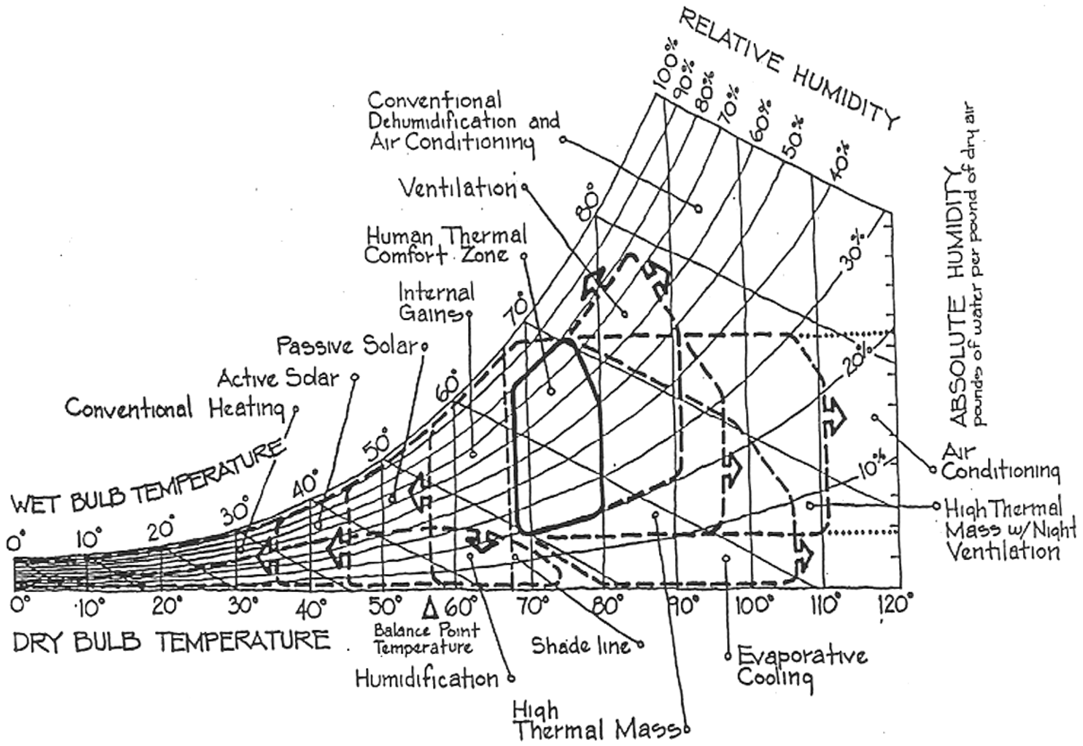

Figure 2.13 Givoni's Building Bio-Climatic Chart (BBCC).

2.5.4 Fanger's Heat Balance Equation and Predicted Mean Vote (PMV)

Many of these methods (i.e., Givoni's BBCC and ASHRAE's) overlap the comfort range on top of psychrometric charts. However, this makes the use of these methods limited. Fanger uses an alternate mathematical model to evaluate the human comfort aspect, suggesting that a measure of human thermal comfort might be derived from the equation of heat balance. According to Fanger (1970), the degree of comfort can be established through a subject's vote on a seven-point ranking scale, (Figure 2.14).

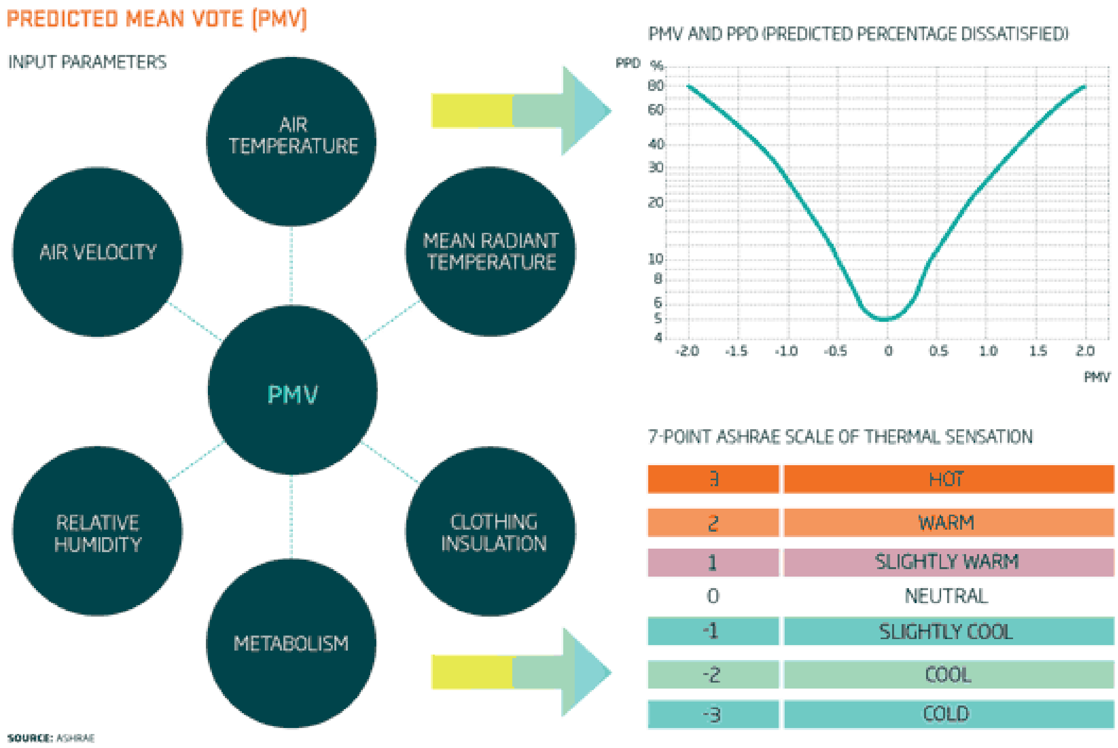

Figure 2.14 Seven-point ranking scale.

2.5.5 Corrected effective temperature (CET)

CET can be definite as the temperature of a still, saturated atmosphere, which might generate the similar result as the atmosphere in question. The CET merged the influence of four variables: temperature, humidity, air movement and radiation. This scale is currently the most widely used one.

2.5.6 The Mahoney tables

This concept developed by architect Carl Mahoney in 1968 in Nigeria was published in 1971 by the United Nations Department of Economic and Social Affairs. A series of tables named the Mahoney tables are used to calculate the comfort limits for any location in terms of it is annual mean temperature and average relative humidity.

The Mahoney tables are used to define the months of the year when shading will be required, based on occupants' comfort limits. The first part of the tables is used to record the most important climatic data, directing and defining the extent of data search. The "humidity group" for each month according to the following categories of average relative humidity is then established. The second part of the tables is used to specify the months where shading is needed the thermal stress exceeds the occupants' comfort limits. The use of these tables enables diagnosis to be carried out and translate into recommended specifications very quickly.

The use of the Mahoney tables to define the shading period is not always necessary, as this data is sometimes already available for major cities and settlements in the preferred comfort range.

Comfort indices have recently become available in the form of a computer software program "***PsycPro***" which is a psychrometric chart and analysis tool and also "***Climate Consultant***" which maintains all the qualities of the manual indices, but is far more accurate and quick. It graphically displays weather information in a number of ways valuable to architects, including temperatures, sky cover, and percentage of sunshine, psychrometric charts, sun charts and sun dials showing hours when solar gain control is required. The psychrometric analysis, offered by this program recommends the most appropriate design strategy, as previously outlined by Givoni (1976).
Internal physiological comfort in summer under air conditioning (room with windows closed) for people acclimatized to a hot, dry climate can be maintained as long as the indoor temperature is kept below 27-28^{o}C. Recently, a number of studies on human comfort have focused on developing countries in hot-arid climates, where people are used to living in unconditioned buildings (Ezzeldin, 2004).

2.6 Solar gain control devices in residential buildings

This part going to review the forms of building and environmental design that can contribute to temperature control, where solar gain is the main factor affecting the temperature in buildings, in fact that there are arrange devices used in building design, both traditional and modern to control solar gain. The main role of any solar gain control device is to protect openings from direct solar radiation, while its secondary role is to protect openings from diffuse and reflected radiation Figure 2.15. These objectives differ according to the latitude, location, type of building, the specific use of the various spaces and the comfort conditions expected (Santamouris & Asimakopolous, Passive Cooling of Building, 1996). Although the need for reduction of the solar gain varies according to the climate, the controlled access of day-lighting is essential throughout the year and is a priority that should be taken into account before the design of any shading device (Santamouris & Asimakopolous, Passive Cooling of Building, 1996).

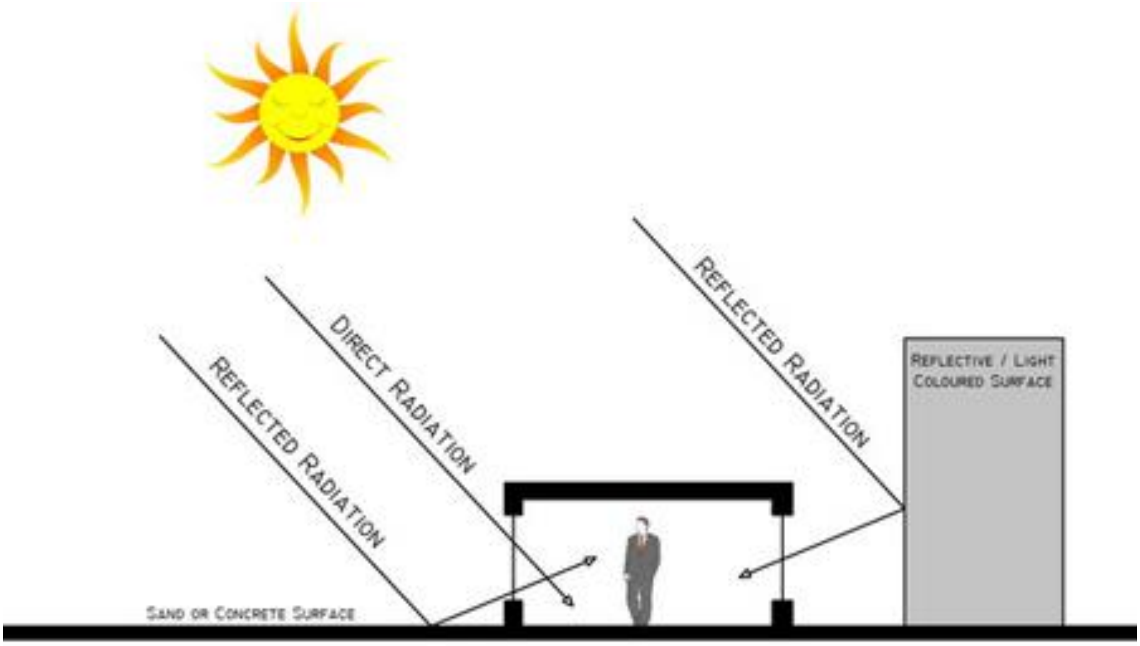

Figure 2.15 Direct and in-direct solar radiation.

Controlling solar gain of a residential building envelope is related to user activities in the building, as well as the buildings' mass and its ventilation system. Therefore, solar gain control devices need to be considered as systems rather than isolated elements (Thomas & Fordham, 2001). The unique features distinguishing residences from other types of buildings, with respect to cooling load calculations, are (ASHRAE, 1993):

1. Residences are regularly busy for 24 hours a day, during almost all days of the cooling season.
2. Internal loads, mainly those from occupants and lighting, are small in comparison to those in commercial or industrial buildings.
3. Most residences are air-conditioned as a single zone. Unit capacity cannot be redistributed from one place to another as loads change from hour to hour.

Solar gain control can be defined as the prevention of the sun's rays from reaching and entering the building. This can be achieved through a number of devices and design features, which will be discussed in the following sections (Stack, Goulding, & Lewis, 1999).

2.6.1 Urban design

In order to design a residential building which has low energy consumption, especially in hot climate regions, the architect has to address the general geometrical factors related to the building's height in relation to the street dimensions, and also the orientation of the facade and the building's form as well as proportion. These factors are outlined in the following subsections.

2.6.1.1 Site location and planning

Selecting the appropriate site for a new settlement or large housing development can avoid serious environmental problems. Roaf (2007) explains that carefully choosing the correct location in the street, such as the sunny or shaded side, the presence or absence of trees, the orientation of the street in relation to the sun and the prevailing winds, the width of the street, are all factors influencing the temperature of the air entering the house (Roaf, Fuentes, & Thomas, 2007). Thus, site location and planning for solar heat reduction in residential buildings involves the evaluation of a number of critical relationships between the buildings themselves, between the buildings and the topography of the site and the overall harmony between buildings and natural, and or artificial land forms (O'Cofaigh, Owen, & Fitzgerald, 1999).

Orientation

The expression "orientation" of a building generally means the direction in which the main facade or facades with common glazing area face. In buildings that have a non-square plan, it is significant that the longest interfaces that are glazed are regarded as the main elevation (Baker & Steemers, 2002). Orientation in response to local climate is an ancient design strategy used extensively in vernacular architecture. The orientation of a structure determines the solar introduction of the building, which has to be simply shaded through summer and maximized through winter. The architect has to take advantage of the shadow made by the topography and design the building in the mainly shaded area (Bourbia & Awbi, 2004).

Generally, north and east facing slopes receive less direct radiation then west and south slopes. For the period of summer, a north slope is the shadiest and coolest, at the same time the west slope is the warmest in winter. In hot and dry climates, a south-east orientation is the most beneficial. Moreover, in areas which are cold in winter, the base of a south facing slope is mainly preferable, although in areas with mild winters; east and north facing slopes can be used (Santamouris & Asimakopolous, 1996).

According to Baker and Steemers (2002) there are several advantages in the major facades of a building facing north and south, rather than east and west:

1. The sun is low in the sky in the east and west, even in the summer, which makes shading rather difficult and even impossible if we want to maintain a view.

2. North facing windows get direct sunlight only in high summer, early winter when the sunrises and in the evening.

3. Due to the high angle of the sun when it is in the southern sky, simple horizontal overhangs can easily shade south facing facades.

4. The southeast facades are preferred because solar radiation arrives earlier in the day when the building and ambient temperature is lower.

The only disadvantage of north facing rooms is that they do not receive direct sunlight in winter.

It is usual to relate the direction of the building to the orientation of roads by positioning the main elevation facing the road. As explained above, the southern facade of a building is the one that can be more easily shaded; thus, houses on east-west roads are perfectly orientated for solar access in winter and shading in summer (Santamouris, et al., 2001).

However, providing shading during summer to houses on a north south road can be improved in different ways:

1. Directing the short interface to the main street.
2. Developing a row of houses, detached or terraced, with the long facades facing south-north. Access from the central houses to the main street can be permitted through driveways.

Houses can also be situated diagonally if the street is diagonally orientated. These sites allow for ventilation without hindrance in the home and improve privacy.

When choosing a site for a house on property that is large enough to provide many building sites, designers must aim at natural shading from existing trees and land masses. This shading can be very helpful in decreasing solar gain from the low afternoon summer sun by setting the building to the east of such features (Watson & Kenneth, 1983).

The term street effect is used to describe the masking effect caused by buildings positioned across the street. It depends on the buildings height and the length between them as well as latitude location and orientation of the street (Santamouris M. , 2008).

Obstructions and overshadowing

Obstruction can shade houses from part of the direct sun at certain periods of the day and year. They can be quite far away mountains or other terrain formation which implies that the shading will be over the whole building. If other buildings or vegetation are close to the house, only parts of the house will be affected by shading, a factor which needs to be studied at early stages of the design (Baker & Steemers, 2002).

The designers also have to take the influence of future building developments into account at early stages of the plan. Hindrance from the south tends to be the most common reason for overshadowing in winter, because of the sun's low altitude. Valleys running east-west, as a result, face the maximum hazard of permanent overshadowing. Neighbour buildings to the south might produce a similar result (Lewis, Goulding, & Steemers, 1992).

According to Yannas,"For every point on a surface, its view of the sun becomes obstructed when the latitude angle of the obstructing object, the obstructing angle θ exceeds the solar angle" (Yannas, 1994) and he also points out that "Solar altitude angles decrease as latitude increases for a set obstruction angle or spacing between houses". The area and period of overshadowing increases from the south in the direction of the north. Thus, an increase in latitude needs wider spacing between houses. The parameters that have an effect on overshadowing are the height and the distance from the affected facade. (Yannas, 1994).

Obstructions can influence the natural lighting provision in a building. If an obstructing building is large or close by, access of sufficient day-lighting can be difficult to achieve. A building that cannot see the sky is gloomy, dark and could be overshadowed (Littlefair, et al., 2000).

A south facing gradient reduces the angle of obstruction at the same time as a northern gradient increases it (Yannas, 1994). South facing slopes receive more sun than ground sloping north; so, a taller building in the south may overshadow lower ones (O'Cofaigh, Owen, & Fitzgerald, 1999)

2.6.1.2 Building form and design

A number of factors, in addition to solar gain reduction influence the designers. The shape and dimensions of the site can create constraints on the selection of building shape, which can influence the possibilities for optimizing the shading, for the most part in dense urban sites. Legislation and planning codes might also inflict a few restrictions on building shape.

The advantages for the control of both heat losses and heat gains extend throughout the building skin (Allen & Iano, 2012). In hot humid environments, buildings tend to contain open extended plan shapes, with a single row of rooms to permit cross ventilation. Such rooms might be reachable from open verandas, which also offer shade (Koenigsberger, Ingersoll, Mayhew, & Szokolay, 1973).

Building height has significant influence on solar gain; in that rising height increases wall area. Because summer radiation is greater on a horizontal facade, it would be more beneficial to decrease roof area and increase building height, as walls are more easily shaded than roofs (Watson & Labs, 1983).

Housing type has a huge effect on envelope exposure and facade shading. The change from detached to semi-detached and terrace houses leads to cuts in wall exposure. Moreover, the form and geometry of the structure envelope have a result on exposure. Multifaceted geometric shapes and projecting wings have a tendency to shade neighbouring facades (Yannas, 1994).

Designers tend to use a number of building forms to shape buildings in a way that enhances their thermal performance. Several of these forms permit partial self-defence for solar radiation omitting, such as the upside down pyramidal shaped structure. In this shape, the upper stories are cantilevered to provide shade for the elevations, as illustrated in Figure 2.16. The façade’s inclination in this case must be determined in accordance with the building orientation and requisite shading stage. It must be recognised, however, that a building with an upturned pyramidal geometry has a larger roof area; therefore, further shading devices must be considered (Nasrollahi, 2009). This form can be used in a multi-story accommodation building. It can be also used at the exterior stage to provide shaded sidewalks for pedestrians, as can be seen in Figure 2.17 (Capeluto, 2003). In quite a few site cases, L-shaped, U-shaped layouts and other irregular shapes are requested. The wings of these forms can shade other facades and sometimes create overshadowing. Small shifts in orientation and direction or the exact proportionality of the wings can reduce this problem (Yannas, 1994).

Figure 2.16 Bank of Israel, Jerusalem (A. and E. Sharon Architects): (a) free view; (b) section.

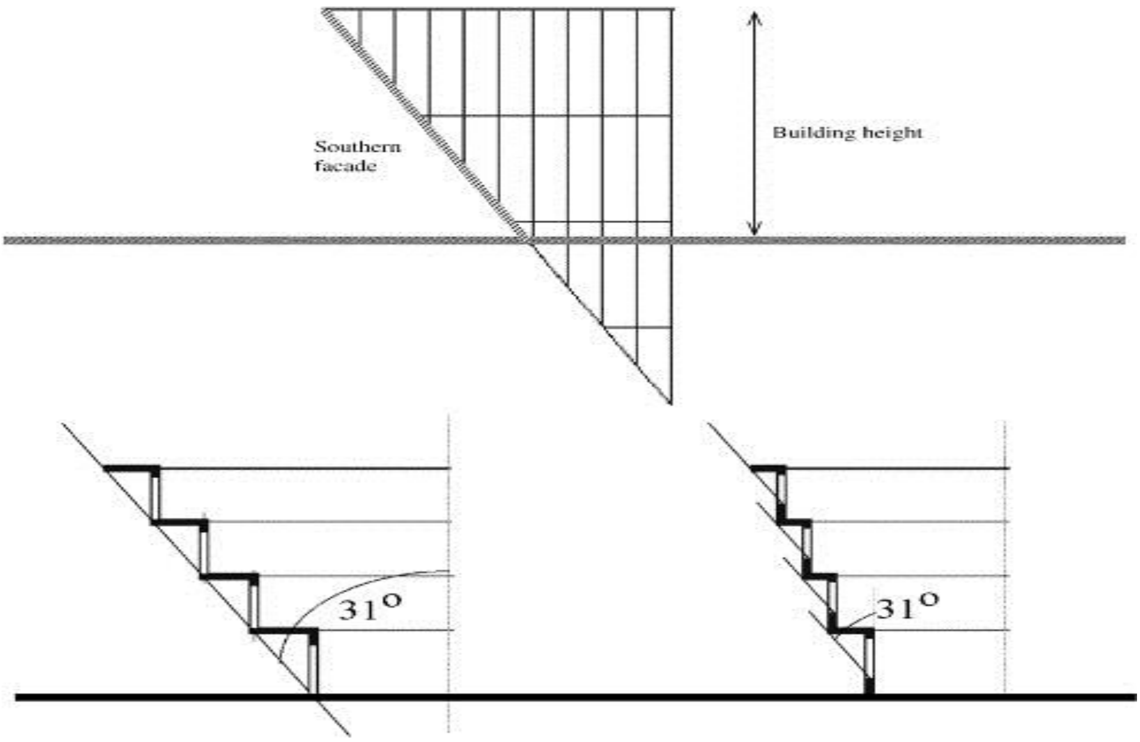

Figure 2.17 Two proposed design alternatives for the southern façade, according to the SCE. Source: Capeluto, 2003

A courtyard is a traditional and effective method for staying cool in hot dry climates. They are considered the most appropriate form of exterior space in a hot arid climate. In this climate, houses share walls and this minimizes the surface exposed to the sun (Figure 2.18). The only spaces that get a large amount of sunshine are the open spaces such as courtyards. At midday, the courtyard receives more solar radiation than the shaded area. As hotter air rises and denser cooler air rushes in automatically, as the cool air is drawn from the shaded street (Sayigha & Marafia, 1998)

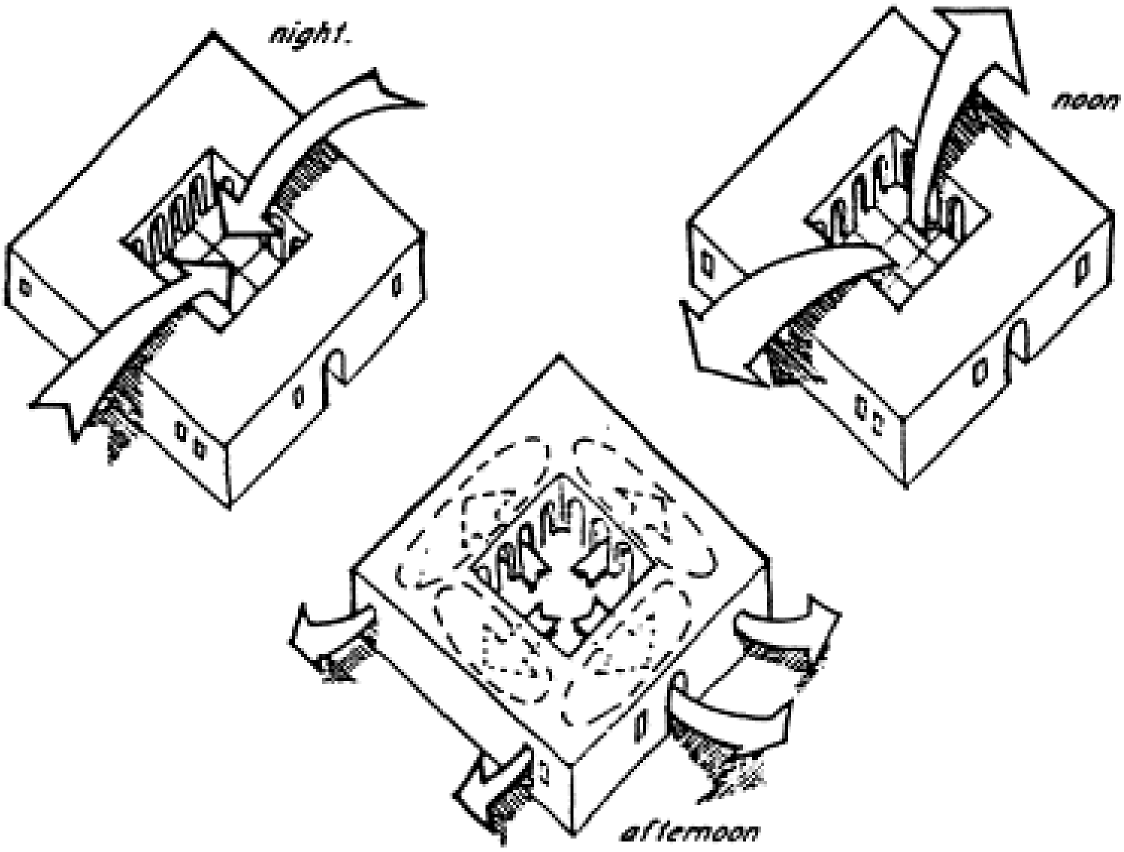

Figure 2.18 The function of the courtyard during the 24 h cycle (Talib, 1984).

Courtyard performance depends to a large extent on the details of the design. If the courtyard is higher than it is wide, it will provide shade for some of its walls during much of the day, even though the sun is high. The main orientation of a court in a courtyard house varies with purpose, i.e. a court oriented along the north-south direction provides greater summer afternoon shadow in the court itself, but the surrounding rooms benefit from the opposite orientation, where they can open either north or south into the court (Knowles, 1985). Other considerations that solar control can also influence the preference of orientation (view, privacy, security, etc.). So decisions about the orientation should be made taking into account also occupancy of the rooms (Yannas, 1994).

Courtyards with high walls cut out the sun, and shade large areas of the inner surfaces and floor of the yard during the day (Koenigsberger, Ingersoll, Mayhew, & Szokolay, 1973). The walls of a courtyard shade themselves during hours with low altitudes, but heat up around the middle of the day, so the courtyard has to incorporate shading devices such as trees or canvas awnings (Littlefair, et al., 2000).

Corridors can also be used as a means to solar control as well as keeping the courtyards private. Although designing a colonnade seems simple, a number of factors that determine its impact on solar radiation control were grouped by Littlefair el al (2000) into five parameters:

1. ***The depth of the colonnade***

The deeper the colonnade the smaller the amount of direct solar radiation that will arrive at the ground. However, the rate of solar radiation drop off is much faster in June than in December or even in March, due to the high solar altitude in June. Intermediate latitudes benefit from this phenomenon, as summer radiation is blocked and profitable spring and autumn radiation maintained. For diffuse radiation, the impact of the corridors gradually increases with depth. In this case, the building itself has an extremely significant impact on open space spread of radiation. Diffuse radiation is reduced by 75% at 0.4 times of the height of the colonnade and by 90% at 1.4 times the height.

2. ***Orientation***

When the colonnade is next to an east facing wall, the solar reduction is more regular throughout the year. The building has a significant impact on the direct solar radiation on the face of the colonnade: at the separation between open space and colonnade, the building prevents the sun for half of the day. The effectiveness of orientation on spread of radiation is much more restricted because it comes from the whole of the sky.

3. ***Height of the building***

The general building height has no effect on solar radiation within the colonnade adjoining it. It might reduce the radiation, which would have been received without the colonnade, but not sufficient to counteract the significance of the colonnade for shading.

4. ***Latitude***

At low latitudes, the benefit of a colonnade is greater because of the higher solar altitudes.

5. ***Width/height ratio of the colonnade***

The space from the frame of the colonnade at which good shading is provided depends on its height. The width/height ratio of the colonnade has not considerable influence on its dimensions. Obviously, a wider colonnade will have a larger area with good shade.

Design of shading devices

Even though individual devices are different in size and shape, the performance of each stays unchanged as long as the solar geometry remains identical. Therefore there may be a large number of combinations of vertical and horizontal shadow angles that might achieve the identical aim, giving the designer a greater freedom of options (Stack, Goulding, & Lewis, 1999).

Shading devices can be generally classified into four main categories, as described in Chapter 2.

A. A single overhang or awning
B. Multiple horizontal devices: louvre blades
C. Multiple vertical devices: louvres or fins
D. Egg-crate devices, e.g. grill blocks.

There are a number of features that influence the design of these devices, in addition to their shading performance Figure 2.19, like construction, materials and cost. Penetration of the sun through the elevation for short times is considered satisfactory, if it is for structural, aesthetic, day lighting, air movement or economic reasons Figure 2.20.

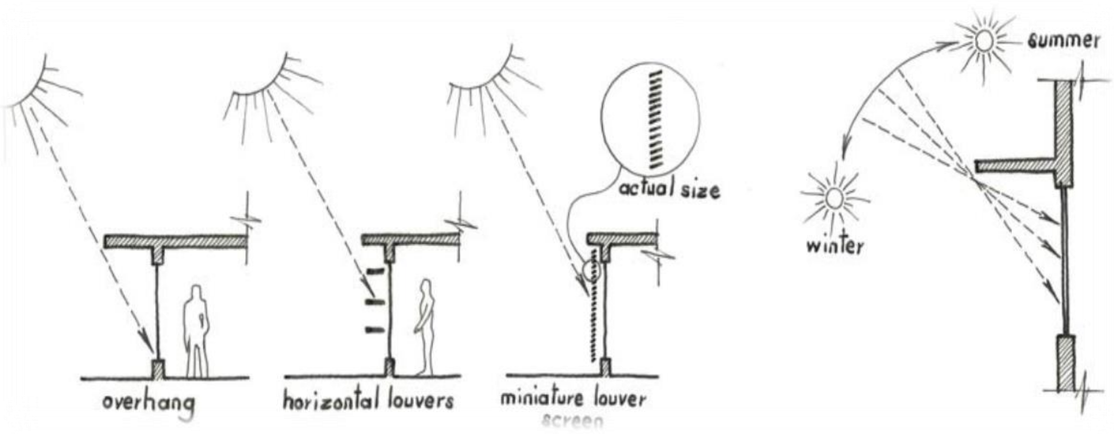

Figure 2.19 Many small elements can create the same shading effect as one large device. Source: (Lechner, 2001)

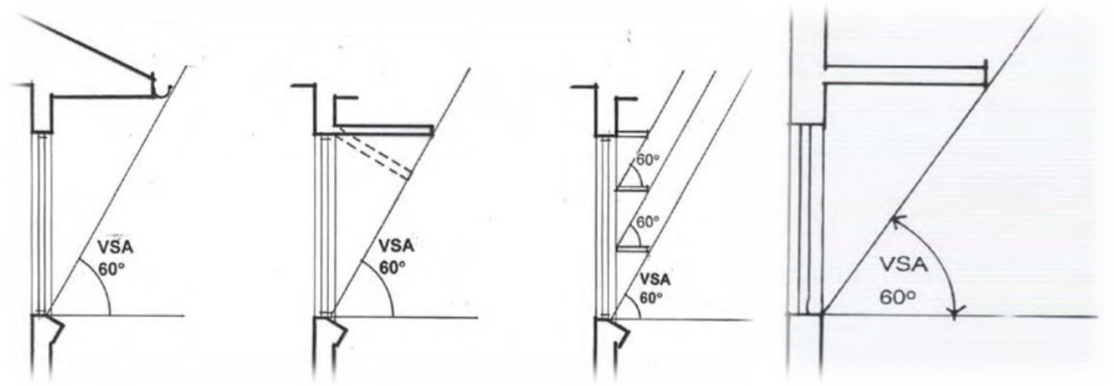

Figure 2.20 Various shading devices for a set performance. Source: (Szokolay S. V., 1980)

Shadow tables

Sketching the shadow created by neighbouring obstacles can also determine the solar access to the building. By tracking the shadow pattern for every building and any other neighbouring obstacle, such as a tree, solar access to a specific space can be calculated. The easier method to recognize shadow patterns is by calculating the shadow produced by a vertical pole. If the altitude of the sun is recognized, the shadow on the horizontal plane of a vertical pole can be approximated by employing basic trigonometric expressions ($s = H/ \tan \alpha$), or inversely, for a particular shadow length, the height of the element that produces the shadow ($H = s \tan \alpha$) can be calculated. The shadow pattern for a whole building is then constructed by assuming that the building is composed of a series of poles. In this way, the shadow created from neighbouring buildings can be studied in the early stages of the design, Santamouris and Asimakopolous (1996) describe the process to work out the shadow pattern on the horizontal plane of a building or any other obstacle as follows:

1. The sun altitude azimuth for the specified latitude day and time is determined. A sun path diagram could be used in this stage.
2. On the plan of the building, the shadow trace from each edge is drawn parallel to the direction of the azimuth angle.
3. The shadow length corresponding to the height of the edge, sun altitude and azimuth is specified.
4. On the shadow trace, the length of the shadow for the specified height, as mentioned in the previous step, is drawn.
5. The shadow length of each edge is connected, producing the shadow pattern of the specified building, on the horizontal plane. The shadow produced on the vertical plane, as it is projected on the façade of neighbouring buildings, can also be drawn.

6. The end points of the shadow trace (c and d) are projected onto the section drawing. The projected end points (c and d) are connected with the top edges of the building that gives shade A and in this way the direction of the sun's beam with the façade of the shaded building B (points a' and b') gives the length of the shadow on the façade (Figure 2.21 Figure 2.22). The intersection of the shadow trace with the shaded building B (points a, and b) is projected on the façade of the latter building on the façade drawing. The shaded area on the facade is defined by transferring the heights of points a, and b.

Following the same method, the solar penetration to the interior of a room can be identified, as shown in Figure 2.23. Also, in a similar way, the geometry of any shading device for the desired period can be known.

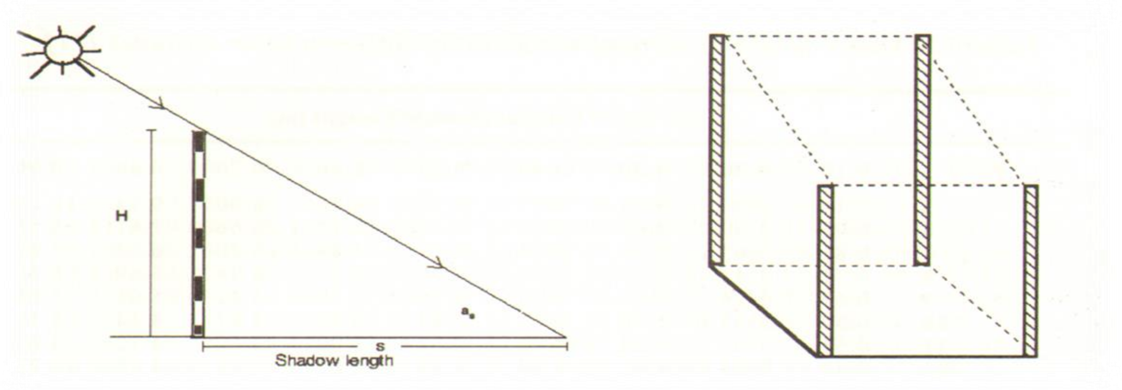

Figure 2.21 Shadow of a vertical pole and representation of a building as a series of poles.

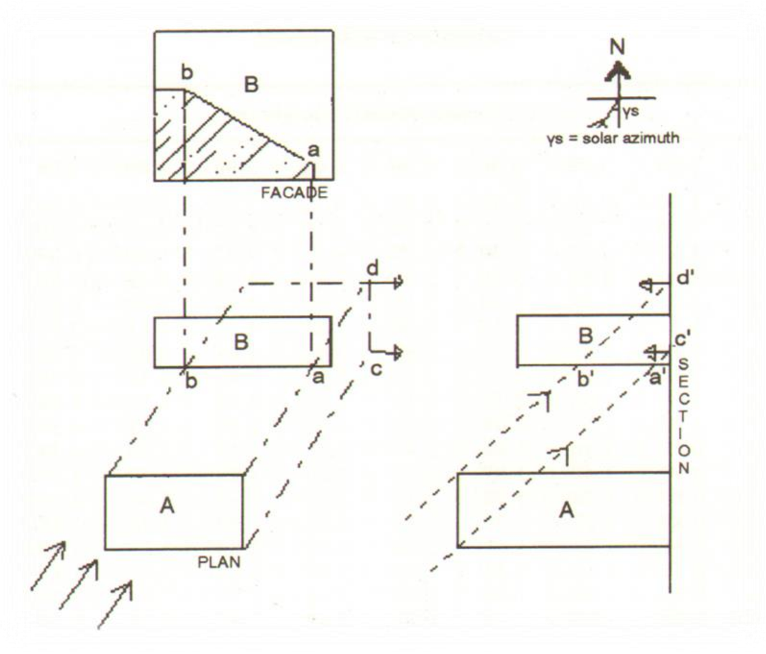

Figure 2.22 Identifying the shading pattern of neighbouring buildings in plan and section.

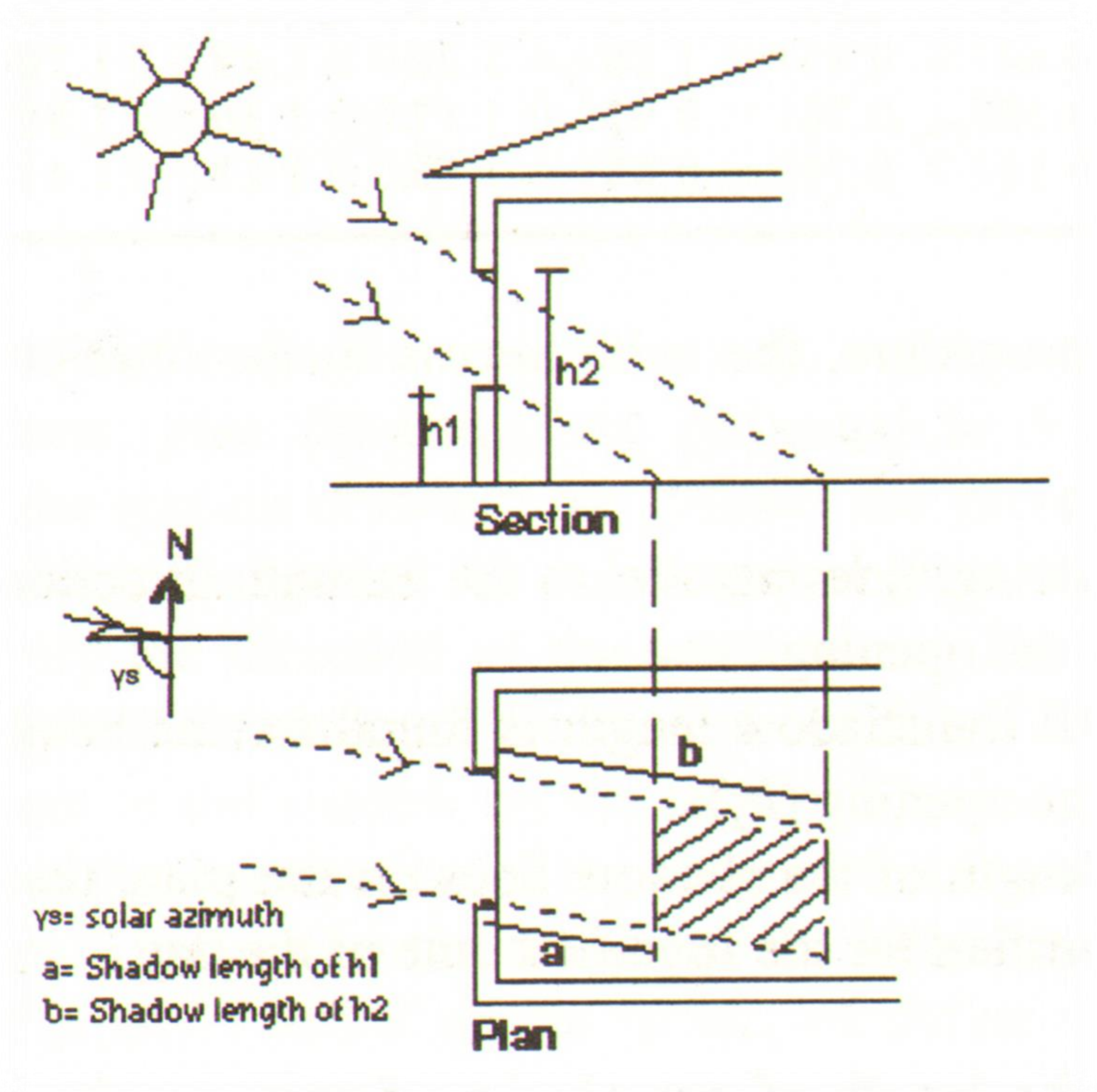

Figure 2.23 Identifying solar accesses to the interior of a room. Source: (Santamouris & Asimakopolous, Passive Cooling of Building, 1996).

2.6.2 Shading devices

Shading design is a very important feature of environmental and comfort design. It is mostly linked to control of the solar gain through the hot seasons but it as well has other significant objectives as mentioned by Santamouris & Asimakopolous (Passive Cooling of Building, 1996):

1. Non-interference with winter solar gain.
2. Control of the strong daylight by spreading it in a uniform way in most of the space.
3. Unobstructed view from openings.
4. Admission and regulation of ventilation air for adjacent spaces.

The period of sunlight in buildings changes according to the changing pathway of the sun. The sun's location relative to the building elevation can be represented by the angle of incidence and shadow angles. Once all requisite shadow angles have been recognized, the plan of the form of a shading device will be easy.

The geometry of the sun's path and its relation to the earth is exactly known, which enables the designer to predict solar altitude and azimuth. This is frequently represented by the sun path chart. The altitude and azimuth angles differ in accordance with the sun path and can be drawn on a sun path diagram for the whole year.

2.6.2.1 Types of shading devices

The option of the appropriate shading device depends on the latitude, sky conditions (the direct, diffuse and reflected solar radiation components) orientation, building type and overall design of the building (Santamouris & Asimakopolous, 1996). Such devices can be used to decrease heat gain through the day and the heat loss through the night, as long as they are of appropriate design and orientation (O'Cofaigh, Owen, & Fitzgerald, 1999).

Orientation of the windows, combined with their size, can decrease the solar gains passing through them in the following ways (Santamouris & Asimakopolous, 1996):

1. North oriented windows get limited solar heat gains (at early morning and late afternoon hours during summer).
2. South oriented windows get high solar heat gains during winter, while they can simply be shaded during summer due to the high position of the sun in the sky.
3. Siting of east and west oriented openings is a problem due to the low sun position in the sky. It is advisable that openings in this side should be as small as possible or exchange with other orientated openings in these facades.
4. Skylights present problems in shading because they face the sun directly.

Shading devices may be fixed or movable or retractable and may be placed externally, internally or within double glazed panels. Vegetation can also be considered as an external shading element.

External shading devices

Windows completely shaded from the outer surface decrease solar heat gains by up to 80% (ASHRAE, 1993). Once infra-red radiation has entered through the glazing into the building, the majority of it is captured and has to be dissipated by ventilation or air conditioning units (McNicholl & Lewis, 1994). In which they are additionally expensive to fit and present a problem in their repair but they play a significant role in visual character on elevation (O'Cofaigh, Owen, & Fitzgerald, 1999).

Adjustable external shading devices include shutters (hinged, sliding, etc) rotatable fins, horizontal plates, retractable venetian blinds, or canvas awnings. They can be made of various materials, such as wood, different metals or fibre. Many exterior shading devices can cut off solar radiation reflected from the floor, as well as intercepting the direct and most of the reflected radiation from the sky, as shown in Table 2.1 (Givoni, 1994).

External shading devices can be of three basic type’s figure 2.24:

1. Vertical devices: these consist of aperture blades or fins in a vertical position.
2. Horizontal devices: these could be canopies, horizontal louver blades or externally applied venetian blinds.
3. Egg crate devices: these include various types of grill blocks and decorative screens.

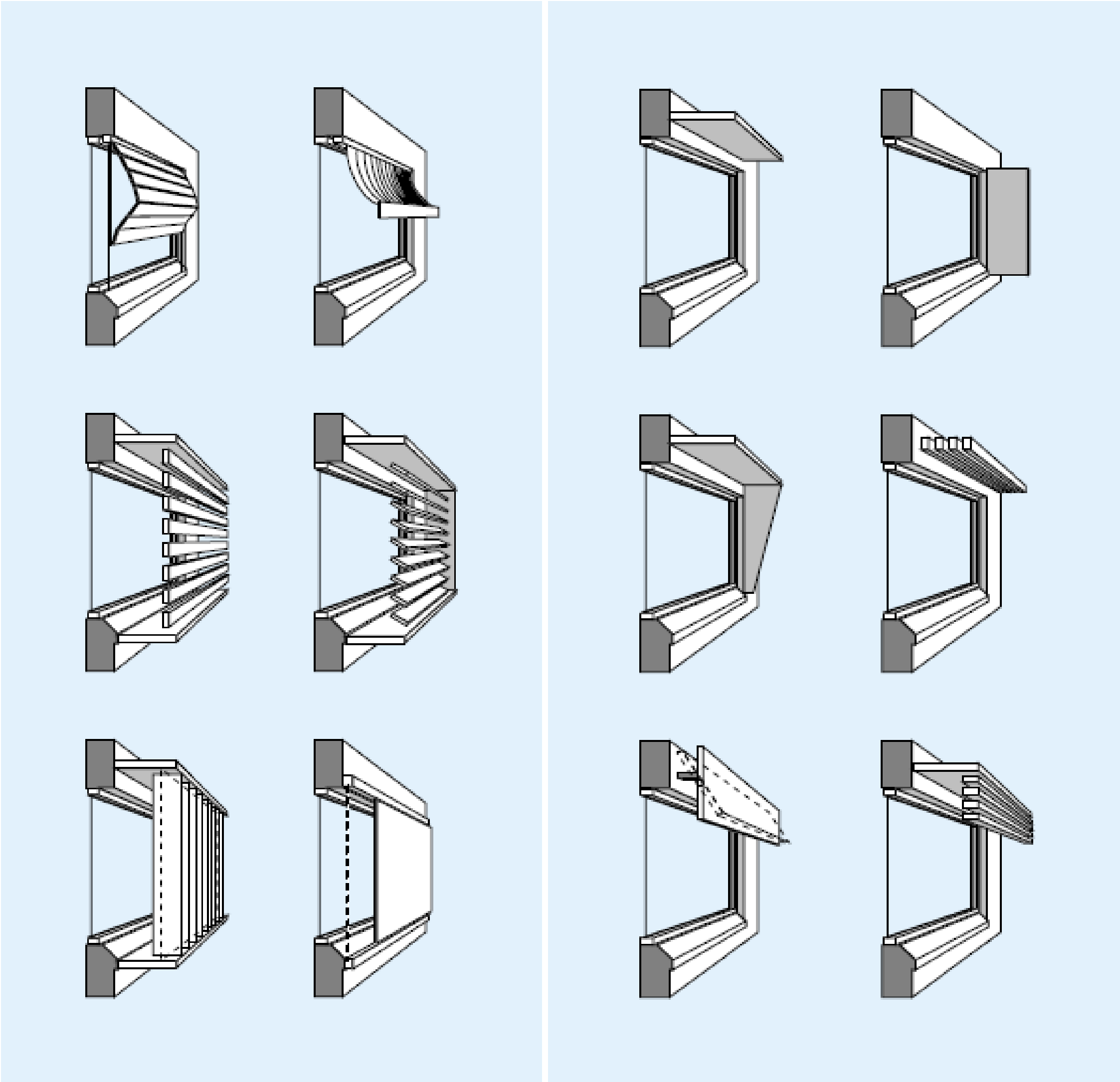

Figure 2.24 Solar radiation transmission through external shading (O'Cofaigh, Owen, & Fitzgerald, 1999).

Table 2.1 Solar radiation transmission through external shading.

Colour	% Transmission	% Reflection	% Absorption
Light-coloured, translucent	25	60	15
White, opaque	0	80	20
Dark, opaque	0	12	88

Source: (Goulding, Owen, Steemers, & Directora, 1992)

1. ***Fixed or movable overhangs and canopies***

These devices are used to shade south-facing openings, and are positioned on top of the glazed element. It is important to place the overhang in such a location that it facilitates the passing of the rays through the opening when the sun is low in the sky as can be seen in Figure 2.25. The depth of the overhang must take into account its distance over the window as well as the opening height, although its length is determined by the opening width (Lewis, Goulding, & Steemers, 1992).

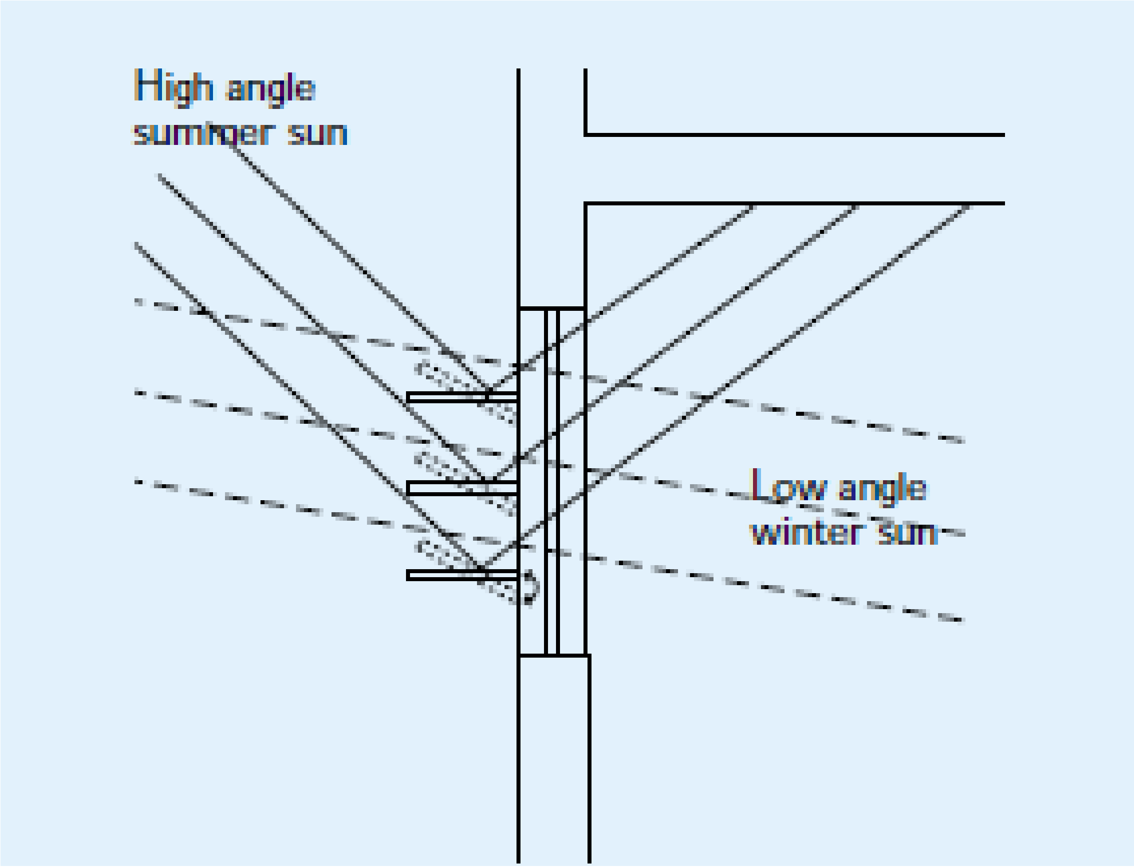

Figure 2.25 Overhang angle

These devices block high angle sunlight and allow the low angle winter sun, although they also reduce daylight diffusion (Stack, Goulding, & Lewis, 1999); for that reason awnings or ductile hangings can be best in northern latitudes (McNicholl & Lewis, 1994). Continuous overhangs provide, to a large extent, more shade than those across the width of the opening only (O'Cofaigh, Owen, & Fitzgerald, 1999).

Long balconies and roof overhang are more suitable in hot climates: in many cases this is accomplished with tents or pergolas as shown in Figure 2.26 (Santamouris & Asimakopolous, 1996).

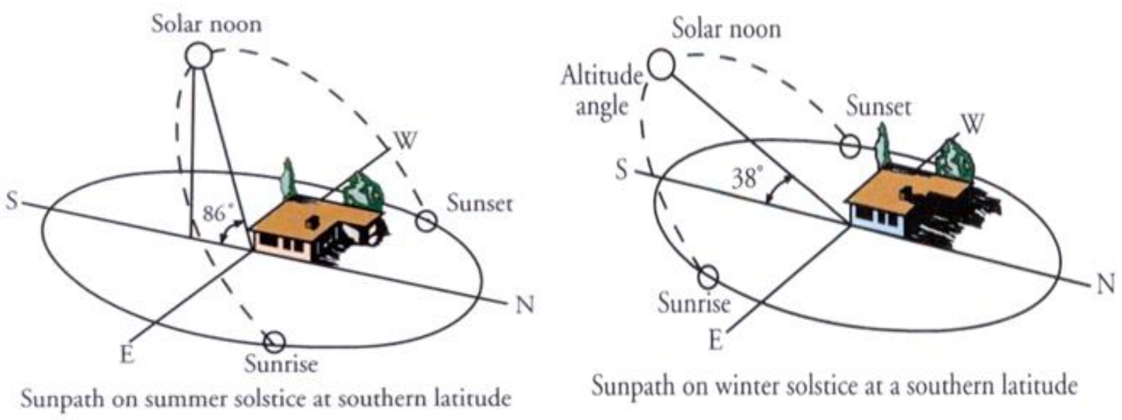

Figure 2.26 Sun path on summer and winter latitude.

2. Light shelves

Light shelves are considered successful devices for the eradication of direct sunlight in the front of the room without dropping the daylight aspect at the back of the room (O'Cofaigh, Owen, & Fitzgerald, 1999). They divide the purpose of the opening horizontally: a bottom part protected by an overhang to illuminate the front part of the room, and a higher part gives illumination for the back part of the room. In a strongly sunny climate, the situation might need an additional overhang on the upper window to avoid direct sunlight from getting to the back of the room (Baker & Steemers, 2002).

3. Fixed and movable louvres

Louvres are the best on the east and west facade. Moreover, horizontal louvres have to be almost totally closed to stop sunlight on east and west elevations. Vertical louvres can be left partly open to allow reflected or spread sunlight from the north, while still blocking direct sunlight (Goulding, Owen, Steemers, & Directora, 1992).

Louvres must be located so as to obstruct the summer sun from shining towards the inside of the building and at the same time allow the access of the winter sun. They also function as a light diffusing device during the summer (when painted white) by diffusing the light into the room below (Santamouris & Asimakopolous, 1996).

4. Shutters

Shutters can be louvered or opaque. Their shading performance changes according to their colour. White shutters are better than dark ones, as they give additional daylight by reflecting the solar radiation inside.

Opaque shutters are classified an efficient tool for daylight control. However, louvered shutters merge the advantages of retractable non-transparent shutters and the light redistributing characteristics of louvers when closed. They can be adjusted to stop direct sunlight permeation and only allow the ground reflected light to go through (Baker & Steemers, 2002).

5. ***Fixed screens***

These devices can be found in tropical buildings, where screens are used in unpainted slots. They do not only offer shade to the window, but they also maintain safety and privacy from outside, at the same time as allowing ventilation (Baker & Steemers, 2002). If the screen is intended to be used in shading the east and west openings, this can determine the dimensions of the width and height of the opening. (Lewis, Goulding, & Steemers, 1992).

6. ***Egg-crate***

The egg-crate shading device combination is the most efficient in the south-east and south-west facades. These are considered as successful for east and west orientations in hot climates and for south-west facades in very hot climates (Santamouris & Asimakopolous, 1996).

7. ***Awnings***

Heat gain can be reduced by 65% in summer on a southern elevation and by 80% on western elevation by adding awnings to the building, as shown in Table 2.2. The required dimensions of awnings are similar to those for horizontal overhangs, but their effectiveness depends on how opaque the material is, as well as the presence of dirt and dust on them, which might vary their absorption characteristics. The effectiveness of material awnings is likely to get worse with age or weather damage (Goulding, Owen, Steemers, & Directora, 1992).

Table 2.2 Solar transmittance of awning materials.

Material	% Direct Transmittance	% Diffuse Transmittance
Canvas	**0**	**0**
Plastic	**25**	**15**
Aluminium (Separated slats)	**0**	**20**

Source: (Goulding, Owen, Steemers, & Directora, 1992)

Internal shading devices

In general, interior shading devices can by simply and easily adjusted and are also able to be used for providing privacy (McNicholl & Lewis, 1994). They can be of several designs, including curtains, roller blinds or others. However, they are less efficient than external shading devices as they reduce only a small portion of the solar radiation which has previously penetrated and been reflected at their surface and transmitted from the exterior through the glazing. The remaining portion of the radiation is absorbed and radiated to the room. In addition, they conflict with day lighting and natural ventilation flowing into the building (Santamouris & Asimakopolous, 1996). Therefore, internal shading devices are unlikely to be suitable for hot regions especially when applied to a large opening (Givoni, 1994). The reflection and absorption properties of an internal shading device influence the amount of solar radiation passing into the building (Goulding, Owen, Steemers, & Directora, 1992). Although it is known that white shading devices reradiate more radiation to the outside compared with dark ones, in the general heat gain of any shading device inside the window is much greater than that of an external shading device (Givoni, 1994).

1. *Fabric blinds and curtains*

Fabric blinds differ in reflectance and transmittance, which has a significant result on their shading/day lighting purpose (Baker & Steemers, 2002). The colour of the blind or curtain determines its shading effectiveness. Light coloured blinds are more effective than those which are dark coloured, because of the effect shown in Figures 2.27 and 2.28 (Santamouris & Asimakopolous, 1996). A study has shown that light coloured internal curtains give as much as 18% additional shade protection compared with by darker ones. It has been shown that an aluminium blind can add an extra 10% more shielding than a coloured one (Olgyay, 1963).

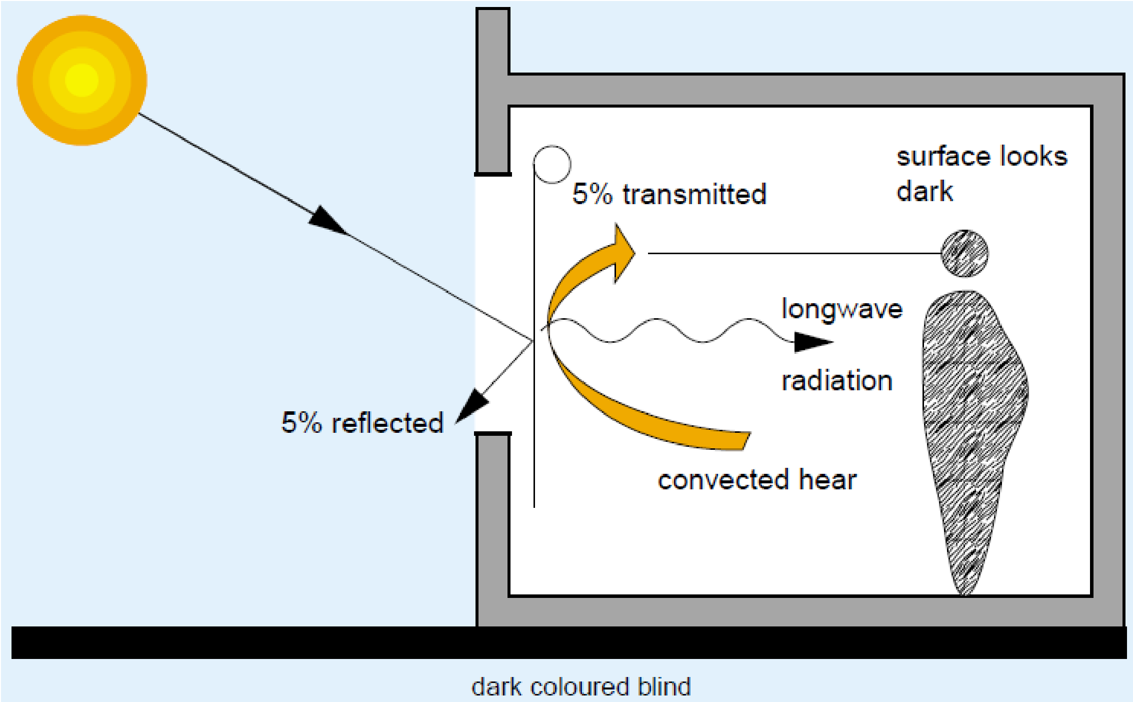

Figure 2.27 Effect of dark coloured blinds.

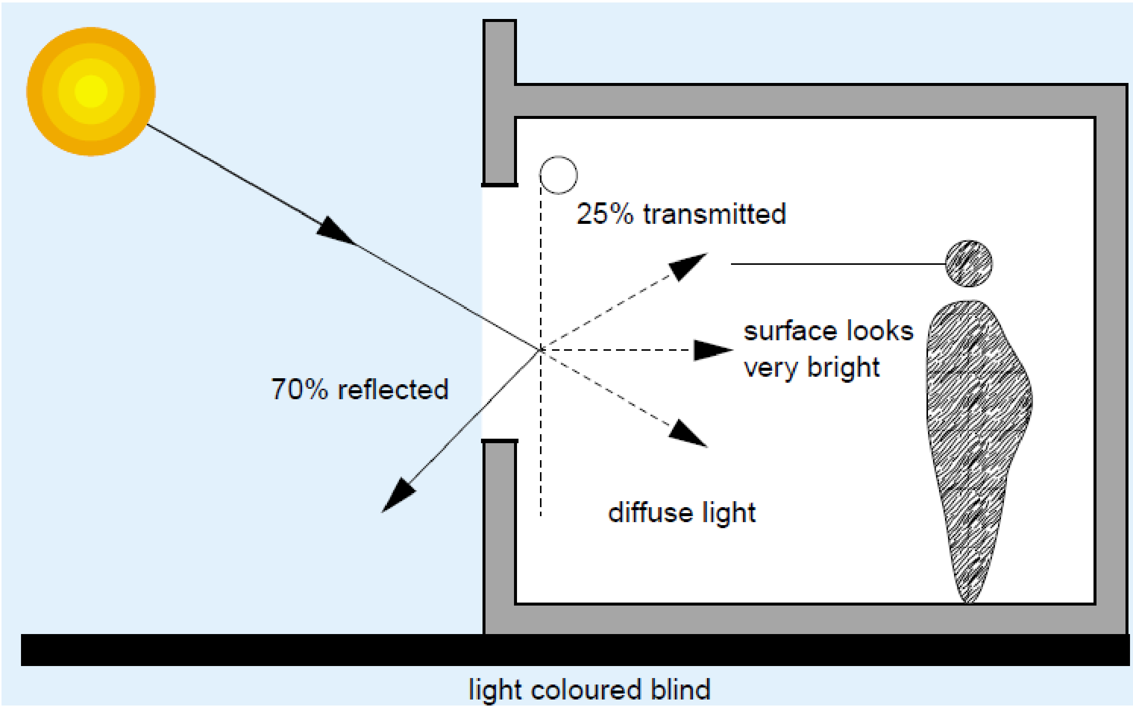

Figure 2.28 Effects of light coloured blind.

Fabric blinds and curtains are not considered as very efficient shading devices because they stop the passage of radiation; they thus absorb the solar heat and can get to an extremely high temperature. Some part of the heat absorbed will be transmitted inside the room air and the rest will be re-radiated. The gap between the window and the blind or the curtain can become very hot (Koenigsberger, Ingersoll, Mayhew, & Szokolay, 1973), therefore glass with absorptive and low emissions must not be used with internal blinds (Goulding, Owen, Steemers, & Directora, 1992). This effect can be reduced by 15-20% with the use of reflective blinds (O'Cofaigh, Owen, & Fitzgerald, 1999).

2. Venetian blinds

Horizontal venetian blinds can be efficient devices in shading the zone close to the window and at the same time they reflect light on to the ceiling and thus to the back of the space (McNicholl & Lewis, 1994) to reduce discomfort due to direct sunlight and permit more penetration of daylight (Table 2.3), although they tend to collect extra dust. Vertical blinds present better light control and have fewer maintenance problems. (Crowther, 1992). For their angular control, raising and lowering are achieved both by hand and by mechanical control. For most effective results occupants must have information on how to make use of such blinds (O'Cofaigh, Owen, & Fitzgerald, 1999).

The effectiveness of shading depends on the colour and material of venetian blinds: an additional 20% of shade protection can be provided by selecting off-white venetian blinds (Santamouris & Asimakopolous, 1996).

Table 2.3 Transmission, reflection and absorption characteristics of venetian blinds (for blind at 45° tilt with sunlight perpendicular to the slats.

Colour	Type	Transmission	Reflection	Absorption
Light coloured	Horizontal	5%	55%	40%
Medium coloured	Horizontal	5%	35%	60%
White	Vertical	0%	77%	23%

(Goulding, Owen, Steemers, & Directora, 1992)

3. Other internal shading devices

Light shelves as well as shutters can be internal, in addition to external shading devices. The louvres are able to be used fixed or rotating internally. However, an inner louvre is not as efficient at reducing solar heat as outer or even mid-pane types (Littlefair P. J., 1999).

Retractable shading devices

“Retractable” shading devices can be totally or partly separated from the window opening. They can take the form of retractable blinds and curtains, as shown in Figure 2.29, and may be either shutters or louvres. It is significant to note that shading devices of this kind have only a small amount of influence on the availability of daylight in the space, for the reason that they can be removed at periods of low light accessibility (Baker & Steemers, 2002).

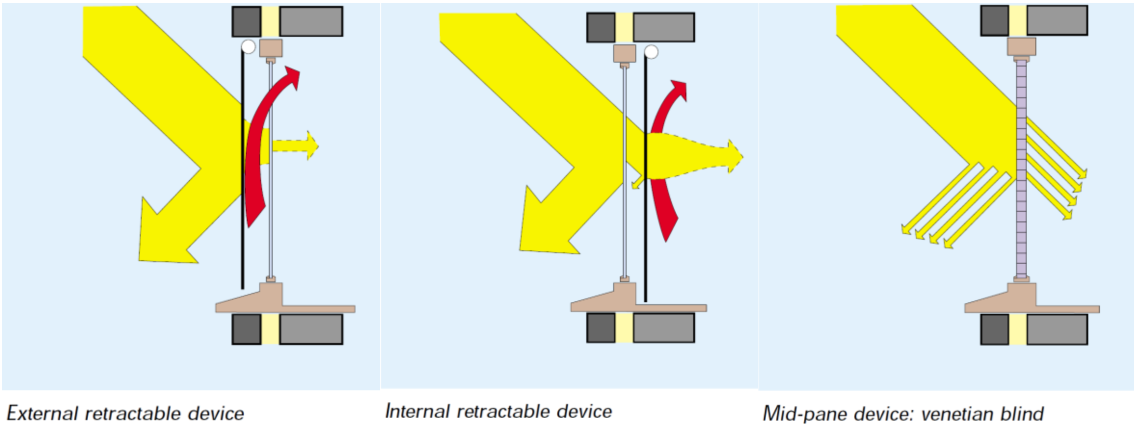

Figure 2.29 Reducing solar heat gain by various types of shading devices (Stack, Goulding, & Lewis, 1999)

Fixed shading devices

Fixed shading devices are a common architectural characteristic. Their proposals should take into account the orientation of the opening to be protected. Their efficiency changes in accordance to the seasonal changes in the situation of the sun (Lewis, Goulding, & Steemers, 1992). On account of this factor, the common use for horizontal fixed shading devices is in southern facades, while east and west facing facades can benefit from sideways shading (Goulding, Owen, Steemers, & Directora, 1992). Vertical fins protect northern openings in the morning and late afternoon hours from the low sun in summer (Givoni, 1994).

Fixed shading includes both structural elements, such as balconies projecting fine or shelves, and non-structural elements such as canopies, louvres and screens. These are commonly used on the exterior facades where they can stop direct solar radiation from reaching the windows and dissipate the absorbed heat to the outside air (Goulding, Owen, Steemers, & Directora, 1992). Occupants of the building choose to install these aids to cooling because of their simplicity, as well as their low maintenance and construction costs (Santamouris & Asimakopolous, 1996).

Mid-pane shading devices

Mid-pane shading devices have been developed to deal with the issue of interference with both views and ventilation, which accompanies the shading effectiveness of mainly retractable blinds and curtains. They can operate either manually or automatically (Baker & Steemers, 2002). There are several kinds of mid pane devices:

1. ***Mid-pane venetian blinds***

Different types of mid-pane blinds are in use. They include blinds with in the air gap of double windows or double skin facades (there can be a gap as wide as a metre between the internal and the external walls of some modern buildings). They generally consist of micro venetian blinds, which can be operated by magnets or by a tiny electric motor. They are more advantageous than internal blinds but difficulty of access can be a problem (Littlefair P. J., 1999). A few types of blind systems use absorptive and reflective specula transmitting films (Baker & Steemers, 2002).

2. ***Mid-pane fixed reflective louvres***

This style of mid-pane device is highly recommended for openings that receive high solar heat gain (especially horizontal or sloping roof lighting). They do not cause much of a problem in their maintenance when they are installed inside double glazing units. The major issue with this fixed kind is they deal efficiently with the sun only for a limited range of solar altitudes (Littlefair P. J., 1999).

3. ***Mid-pane cloud gel***

This gel is sealed between double glazing panes and is normally clear. Above about 30^{o}C, it becomes milky white and opaque, therefore excluding unwanted radiation (Littler & Thomas, 1984).

Reducing window area

Reducing the area of the window is suggested as a strategy for windows which receive a great amount of additional solar heat gain and where loss of day light is not an issue. The disadvantage of smaller windows is the loss of view. The British standard on day lighting (British Standards Institute, 1999) recommends a minimum view window area of at least 20% of the inside window wall, and larger than this for extremely deep areas (Littlefair P. J., 1999).

Comfort windows can provide a similar effect to vertical fins as long as the glazing is close to the inside of the window wall (Littlefair P. J., 1999).

2.6.2.2 Evaluation of the performance of shading devices

Users have a range of different needs from shading devices, such as thermal comfort, low costs, high reliability, aesthetic requirements, compliance with technical conditions (mounting dimensions, dimensions when the blind is fully retracted, etc.) and defence against fire, weather and theft. These requirements cover different aspects: some are important for the choice of a shading device; others are significant for the way the device is used, but thermal and visual comfort are the critical parameters that affect how occupants will manage the device (Kuhn, Bühler, & Platzer, 2000).

Currently there are no established criteria for the evaluation of shading systems, partly because there are such a wide variety of devices on offer. However, a range of methods with various approaches are used to estimate the effectiveness of these non-structural devices, based on calculation of solar gain to the space, or measurement of interior light levels (Stack, Goulding, & Lewis, 1999).

Performance evaluation

Two methods are regularly used for evaluating the effectiveness of various shading devices. The first one is calculating the shading coefficient, which is the relation of the amount of solar energy passing through a protected opening to the amount of energy which would pass through the opening if it was unprotected (Goulding, Owen, Steemers, & Directora, 1992). Pure glasses have a shading coefficient of 1 and while opaque insulated wall has a shading coefficient of zero (Baker & Steemers, 2002).

To calculate the shading efficiency of various materials, Button (1993) recommend the following procedures:

1. For fixed shading devices, take into account the standard daily solar diffusion.
2. For blinds, the standard for all orientation where the slats are to cut out solar radiation.
3. For glass, take into account the total of the short wave and long wave shading coefficients, considered for radiation at standard incidence. For any other incidence angle of radiation, the shading coefficient is compared with that for clear glass in the similar condition table 2.4, which marks in deriving shading coefficients that are approximately at all occurrence angles of solar radiation.

It should be noted that there is a large deviation in the overall transmission with different incidence angles and the orientation as well as the time of the year; therefore, the shading coefficient can be a deceptive guide for judgment.

Table 2.4 Solar gain factors for various shading elements (strictly for UK only, but approximately correct world-wide).

Shading Element	Solar gain factor	Glazing Type	
Position	**Type**	**Single**	**Double**
Internal	Dark green open weave plastic blind	0.62	0.56
	White venetian blind	0.46	0.46
	White cotton curtain	0.41	0.40
	Cream Holland linen blind	0.30	0.33
Mid pane	White venetian blind	-	0.28
External	Dark green open weave plastic blind	0.22	0.17
	Canvas roller blind	0.14	0.11
	White louvered sun breaker, blades at 45^{o}	0.14	0.11

(Goulding, Owen, Steemers, & Directora, 1992)

Based on the evaluation of the shading efficient, it has been concluded that exterior shading devices are 35% extra efficient than interior ones (Olgyay, 1963).

The second technique used to calculate the efficiency of a shading device (particularly its thermal result) is to compare the inside air temperatures with the device to those obtained with the similar windows un-shaded (Santamouris & Asimakopolous, 1996).

Comparative evaluation

Variable shading is more efficient than fixed shading devices for the reason that they can admit all of the wanted solar radiation as it is the situation in winter (Santamouris, et al., 2001).

A number of shading devices can have double roles (McNicholl & Lewis, 1994):

1. Insulation blinds or louvres help in reducing heat loss when closed at night.
2. Treated glass and prismatic strategy offer shading and forwarding of light.

Internal shading devices tend to be cheaper and more easily modifiable than external devices but they are not so efficient at reducing heat gains, as the sunlight heats up the shades and the air in the region of them. Interior shading installed within a double or triple glazed window (with ventilation of the void to the outside) combines the advantages of both kinds, because it permits heat gains to be dissipated to the exterior at the same time as shading the window (O'Cofaigh, Owen, & Fitzgerald, 1999).

1. Orientation evaluation

South facades:

It is possible that a mixture of horizontal and vertical shading devices might be more efficient if the vertical devices are inclined at 45^o to the south (Givoni, 1976). If the designers decide to use horizontal or vertical devices in the orientation, they must be useful, but at the same time, they should not limit the vision or reduce the solar gains during winter season. Horizontal shading is more effective than vertical shading for south-east and south-west orientations (Santamouris & Asimakopolous, 1996).

East and west facades:

Low angle direct sunlight, which is generally common inward on east and west facing elevations, presents problems in shading. Overhangs are not efficient in this case, as the use of fixed vertical fins and rotating ones eliminates a considerable amount of daylight towards the inside of building and blocks the outlook. Internal blinds are able to be left open intermittently and rose according to the sun's angle; however this will increase the heat gain, particularly on west facing elevations. Adaptable external devices are the most effective devices to avoid this drawback even though they are expensive and can result in issues with maintenance and stability (McNicholl & Lewis, 1994).

2. Visual characteristics of shading devices

The visual properties of shading devices were classified by Littlefair, 1999 into two main groups, as follows:

1 Providing a view out

The majority of shading devices affect the outward view, and some sort of compromise is required. This will depend on the principle of the device:

A Controlling overheating

If shading is used just for controlling the overheating, there are a number of devices which protect the outward view: among them are overhangs, light shelves, window film and tinted glazing. Furthermore, coloured glazing and window film must not be dark, or the view will be perceived to be gloomy.

B Controlling glare

The major source of glare is the sun itself. Less often, glare might arise from a vivid patch of sky, or by reflection from a building opposite. The best solution to manage glare and also permit a recognizable view out of the window is usually adaptable opaque shading that occupants can control. Venetian and roller blinds which fall from the top of a window are extremely efficient in controlling high angle summer sun and at the same time allow a view from the lower half of the window.

2 Providing privacy

During the day time, privacy can be offered by transparent shading devices such as net curtains and reflective glazing. Through the night, adjustable opaque shading is required to give privacy. Opaque devices such as thick curtains offer the most excellent screening.

A Loss of Daylight

All shading devices will prevent a part of daylight from reaching the room. In order to make the most of daylight while providing shading, the designer can select one of the following:

1. Adjustable shading that can be withdrawn in cloudy days.
2. Devices that can redirect received sun, such as mirrored louvres. These devices cut off sunlight that would usually cause discomfort to people close to the front of the room.
3. Spectrally selective devices similar to thermally reflective glasses, which permit additional daylight through rather than other parts of the solar spectrum.

The percentage of daylight entering is based on the visual permeability of the shading device. Glass manufacturers usually quote the direct standard transmittance for light passing through the window at right angles. However, the general day-lighting performance is better measured by the diffuse transmittance which includes light approaching in from all angles. The diffuse transmittance is frequently lower than the direct usual value. Clear single glazing has a direct standard visible transmittance of 0.9, but its diffuse value is approximately 0.8.

3. Ventilation characteristics of shading devices

Alternative shading devices have various effects on natural ventilation Figure 2.30 (Baker & Steemers, 2002):

1. Retraction types guarantee unobstructed observation and ventilation when retracted. However, when retracted they do not stop unwanted solar radiation from entering. Louvres, on the other hand, can be used to manage the direction of air flowing if their position is adjusted.
2. Fixed overhangs do not block view while their full shading function is maintained.

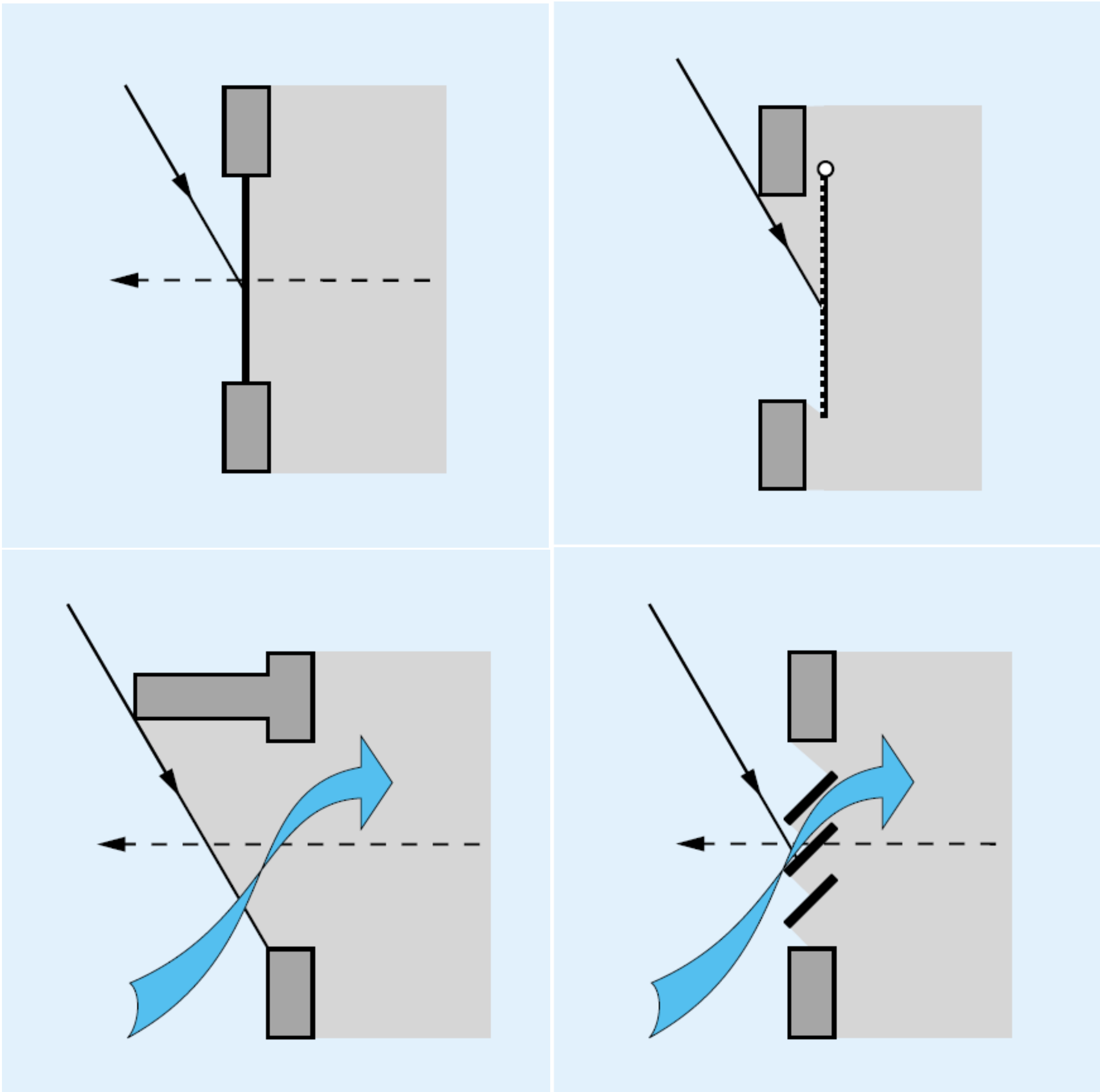

Figure 2.30 The impact of different shading types on vision and ventilation (Baker & Steemers, Daylight Design of Buildings, 2002)

4. The location of shading devices

Various shading devices are able to be installed either inside or outside the glazing, such as fabric blinds, louvres, and screens. It is preferable to situate these devices outside the building so that the majority of the solar radiation is able to be reflected before it reaches the glazing as shown in Figure 2.31. However, this is not usually the case when a shading strategy is used with roof lights, mostly for the reason that convection upwards keeps the heat generated by absorption away from occupants. In this situation, interior blinds take an extremely low thermal penalty, but provide a major reduction in price (Baker & Steemers, 2002).

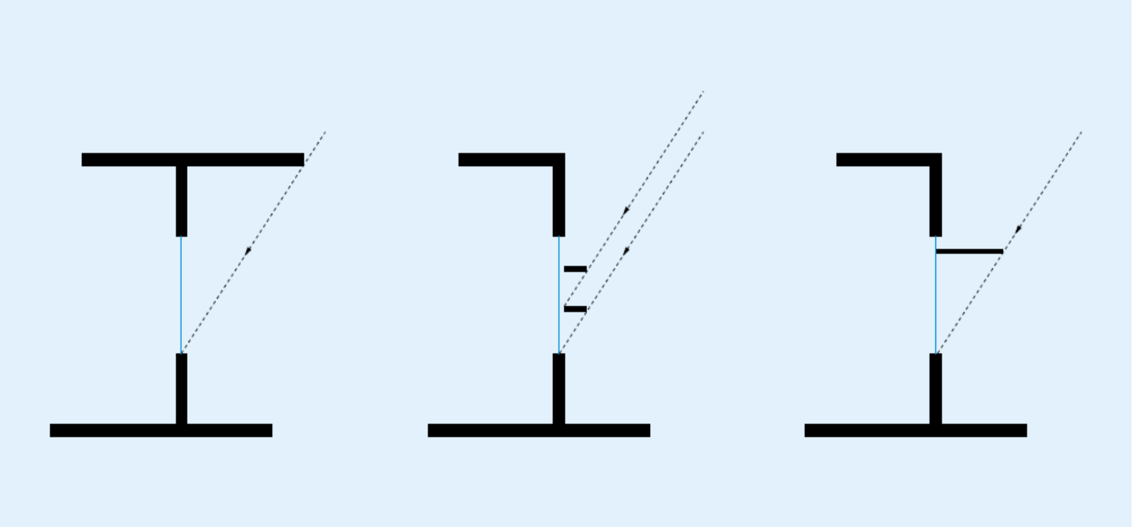

Figure 2.31 External horizontal shading devices with similar performance (Stack, Goulding, & Lewis, 1999)

2.6.3 Vegetation

Apart from the decorative purpose that vegetation provides, it can also enhance the environment around a building and work as a solar gain control device for the surfaces and the buildings. It was verified that a full sized tree next to a building evaporates 1.46Kg of water on a sunny day (Moffat & Schiler, 1981). Bowen found that a shaded area with spread tree canopy was about 22% cooler than an un-shaded area. (Bowen, 1980). Also, extending the vegetation cover by 10 to 30% (one to three trees per house) might decrease the energy requisite for cooling by as much as 50% (Santamouris & Asimakopolous, 1996), while peak cooling costs were reduced by 31-49% (or 3108-4086W) by dense tree shade in a hot environment (in Miami, USA) (McPherson, Herrington, & Heisler, 1988). Generally solar control design using vegetation should take into consideration the range of factors which will be discussed below:

2.6.3.1 Position and orientation

The position of plants around the building varies according to the relation of the attached out space to the residential building as follows Figure 2.32 (Watson & Kenneth, 1983) (Santamouris & Asimakopolous, 1996).

- Tall growing species have to be planted to shade both the roof and wall.
- If the winter winds are west or north-west, the planting could be doubled as a windbreak.

Deciduous vines, such as grape drop their leaves in winter allow the suns heat to hit the building Figure 2.33. Vegetation takes up the suns heat all during the day and produces cooler microclimates Figure 2.34. Trees cool building not only by shading, but in addition by cooling the air surrounding them through a procedure called evaporate transpiration (using the heat to evaporate water), consequently cooling daytime temperatures. The shading coefficients for vegetation vary from 0.20-0.25 for a dense tree, to 0.50-0.60 for a non-dense tree (Jorge, Puigdomènech, & Cusidó, 1993)

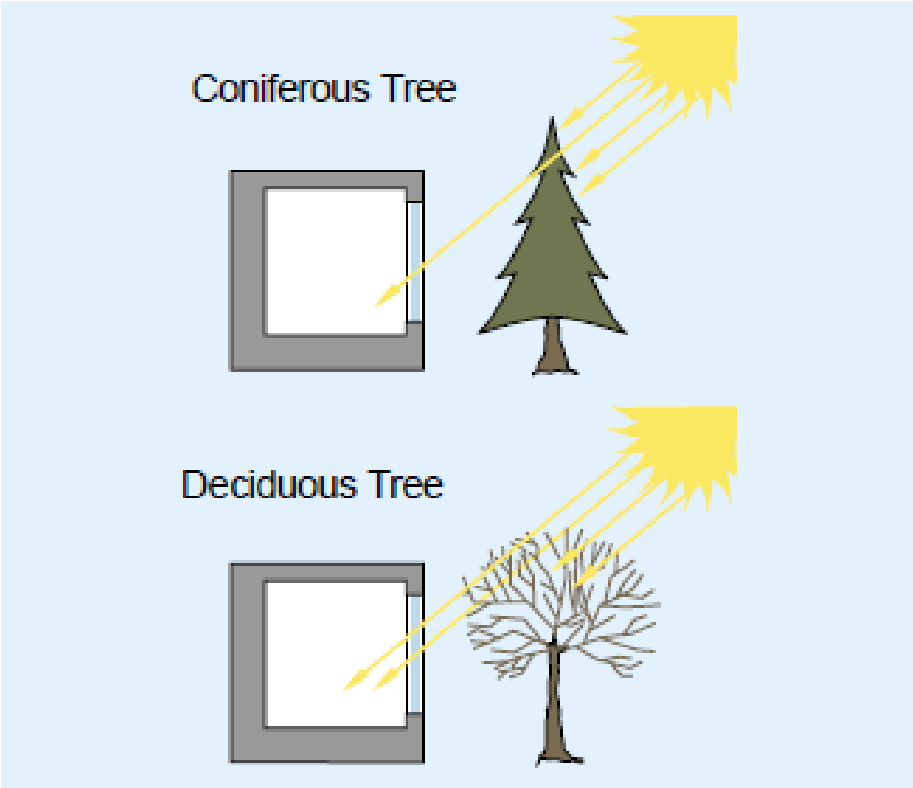

Figure 2.32 Examples of vegetation as a solar gain control device in attached outdoor spaces in residential buildings (Watson & Kenneth, 1983)

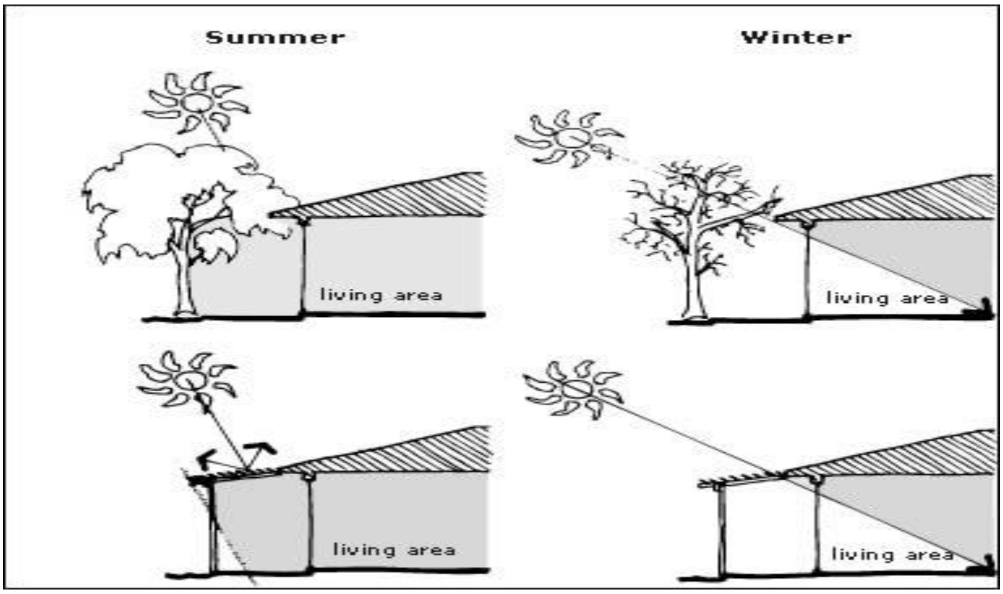

Figure 2.33 Summer and winter heat hit the building.

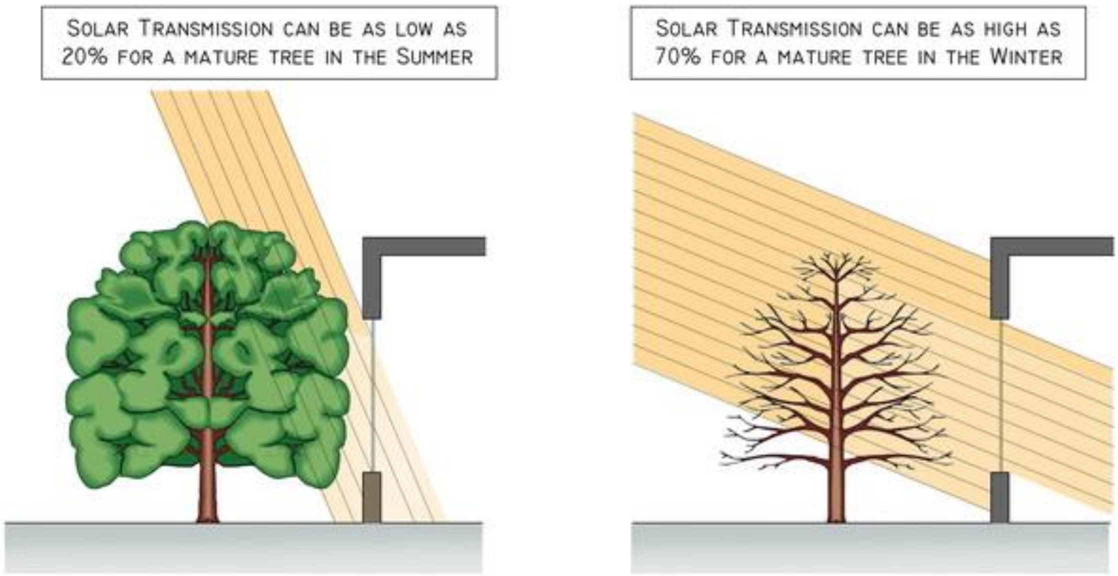

Figure 2.34 The carbon neutral design project.

2.6.3.2 Choice of Vegetation

The option of vegetation (tree or bush) must be based on form and nature, both at some stage in the winter and the summer time. The most effective plants for good siting are often local plants, as they are adapted to the local climate. For best use of vegetation, considerations have to be taken regarding the availability of water in the area, the cost of maintenance and their particular biological requirements (Al-Qeeq, 2010).

Occasionally, there might be several effects linked with trees that have to be taken into consideration in the beginning of the design stages (Akbari, Pomerantz, & Taha, 2001) (Santamouris M. , 2007):

- Several tree types emit volatile organic compounds (VOCs).
- Tree roots are able to harm foundations, sidewalks, and underground pipes.
- Planting suitable tree species as strategically as possibly can minimize these troubles.

The purpose of shade trees in any cooled attached outdoor space is not only to stop the sun, but also give separation between the coldest air under the shading and the hotter ambient air on top of it. The completion of those two functions can successfully be offered together by trees with high trunks and wide canopies and as well by pergolas made of vines with relatively thick foliage. For the duration of the night the canopy tree cuts off direct heat loss radiant from the outside space to the sky, since emission is emitted just from the higher cover of leaves. However, the air under the canopy is hotter than the air on top of it, plus the air that has cooled by contact among the higher leaves can sink down to replace it (Givoni, 1994) and (Bodart & Evrard, 2011). Trellises are constant structures that partly shade the external surface of building. Clinging vines rising above the trellis add extra shade and evaporative cooling. Quick growing vines generate shade fast, while trees can take years to give valuable shade.

2.6.3.3 Density of foliage

One of the major considerations in using vegetation for solar gain control is the location and density of foliage. Plants with dense foliage and few branches ensure maximum protection from the sun in summer and minimum shade in winter, when even bare trees are able to prevent about 20-40% of the sun's rays, as shown in Figure 2.35 (Goulding, Owen, Steemers, & Directora, 1992). Branches of trees produce significant shade that can achieve 30% to 60% for the duration of winter. Broadleaves and deciduous trees are extremely helpful because they drop their foliage through the autumn and offer access to daylight in winter. Other considerations like growth rate, fully grown height, and suitability for weather and soil, as well as root growth and maintenance must be kept in mind (Goulding, Owen, Steemers, & Directora, 1992). Types of trees suitable for the Libyan region are shown in Table 2.5.

Table 2.5 Typical tree canopy densities for Libyan region.

Tree species	Common name	Density
Acer griseum	Paperbark Maple	76-85%
Acer macimowixzianum	Nikko maple	90-93%
Acer platanoides	Norway maple	90-96%
Acer rubrum	Red maple	78-84%
Fraxinus pennsylvan	Red Ash, Green Ash	87-89%
Ginkgo biloba	Ginkgo, Maidenhair	74-82%
Gleditsia triacanthos	Honey Locust	49-50%
Quercus bicolour	Swamp White Oak	81-84%
Quercus macrocarpa	Burr Oak	87%
Quercus palustris	Pin Oak	64%
Quercus ruba	Northern Red Oak	76-80%
Quercus velutina	Black Oak	74-88%

Source: (Goulding, Owen, Steemers, & Directora, 1992)

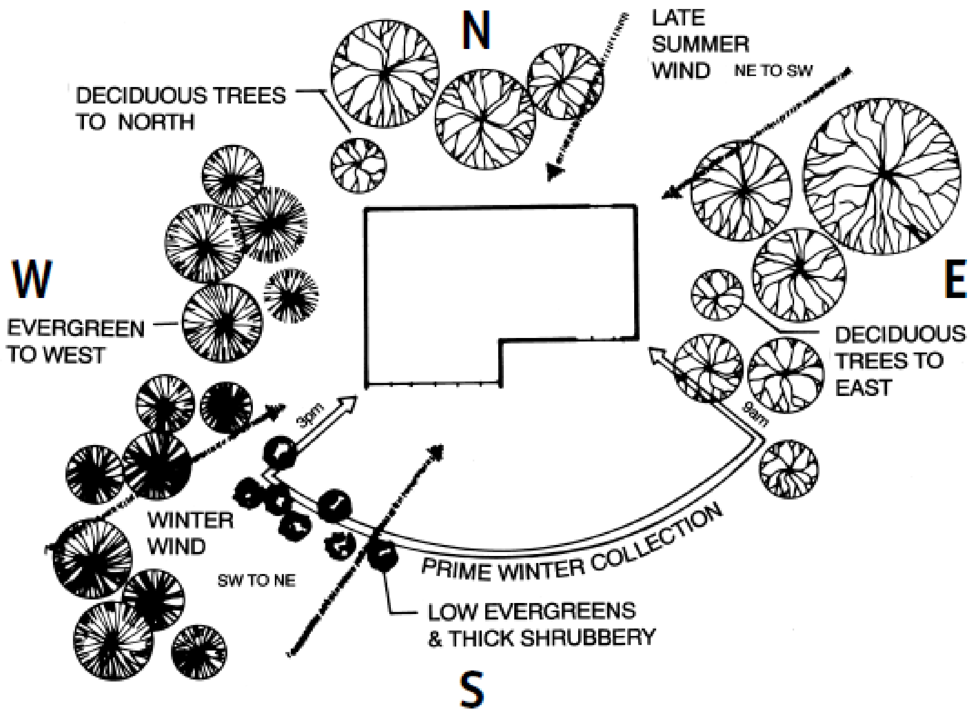

Figure 2.35 The siting of deciduous and evergreen trees around the house.

2.6.3.4 Green roofs

Green roofs, also called vegetated roof covers, or eco roofs, are thin layers of living plants which are installed on top of normal flat or sloping roofs as a solar gain control device. Covering conventional roofs by green roofs can considerably decrease the temperature on the upper surface of the roof. According to Emmanuel (2010) green roofs have the ability to improve the surrounding air temperature and can also reduce the building cooling energy levels for the desired indoor temperatures (Emmanuel , 2010). However, their advantages will be less significant in a multi-story residential building, due to the low ratio of roof area to the whole of the exposed building skin, as shown in Figure 2.36.

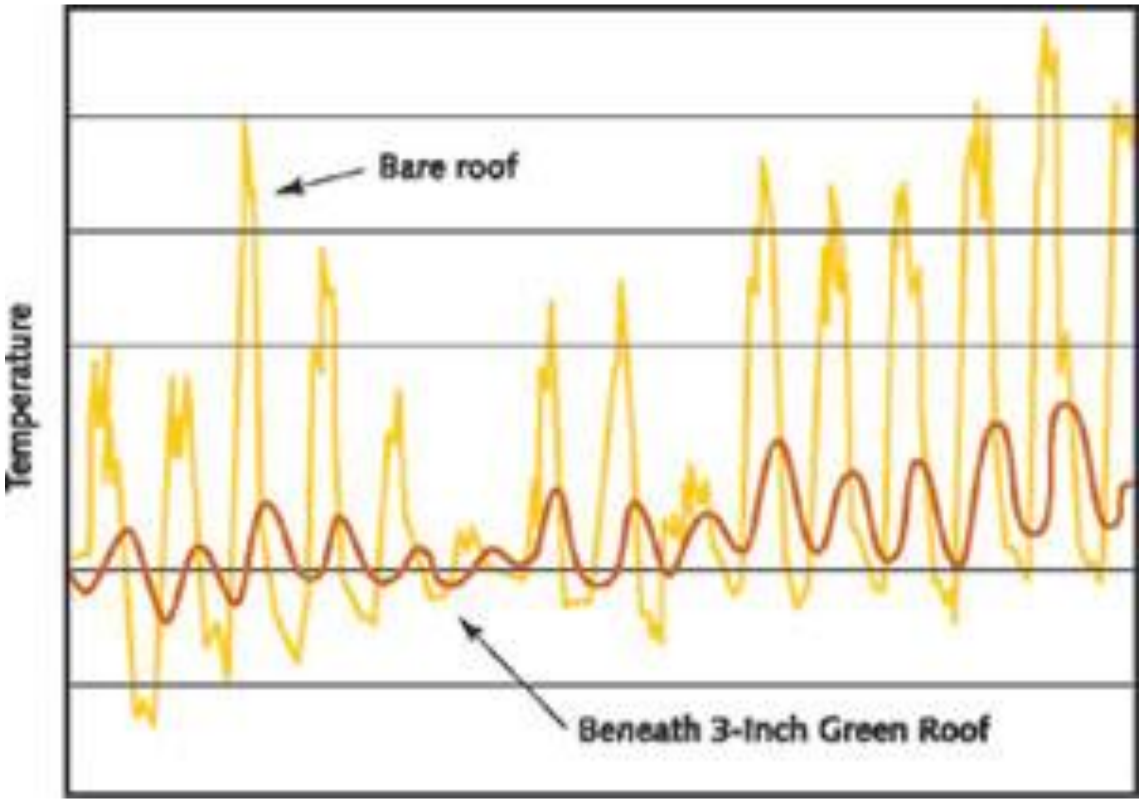

Figure 2.36 Comparative temperature chart. Source: Miller, 2012

Miller (2012) categorises green roofs as follows:

1. *Intensive green roofs*, which are quite deep and can be developed into recreational landscape areas, with recreation areas, extensive perennial vegetation, and trees.
2. *Extensive green roofs*, which are 6 inches or shallower and are predominantly used to control solar gain solar gain in housing buildings (Figure 2.37).

All fully planned wide green roofs need to contain dependable sub-systems for:

- Drainage: The green roof drainage plan should maintain the best growing conditions and also handle serious rainfall with no long-term damage due to corrosion.
- Protection of the underlying insulation system: the green roof should protect the base insulation layer from human actions as well as the effect of repairs.

There are a wide variety of strategies which can achieve these aims. For example, drainage layers can contain rubber sheets, fabric, or artificial mats. However, the substantial functions and performance characteristics of the equipment in place might differ with the weather, the plant community established or engineering needs.

Figure 2.37 Generic extensive green roofs on a steel deck (Miller, 2012)

There are many interacting factors which green roof designers have to take into account, balancing several considerations to ensure the most effective and advantageous performance, including:

- Weather, particularly temperature and rainfall patterns.
- Strength of the supporting structure.
- Size, slope, height, and directional orientation of the roof.
- Insulation and waterproofing medium / materials used.
- Drainage, such as drains, scuppers, buried conduits, and drain sheets.
- Cost of materials and labour.
- Accessibility and intended use.
- Visibility, compatibility with architecture, and owners' aesthetic preferences.

It also has to be noted that their main disadvantage is watering problems.

2.6.4 Control of the solar optical properties of the opaque and transparent surfaces

The materials surrounding the occupants of a residential building are important for protection against heat and cold. Selecting opaque, materials and deciding their thickness requires great care, taking into account their physical properties, such as thermal conductivity, resistivity, transmission, and optical reflectivity.

2.6.4.1 Opaque Surfaces

In relation to temperature difference, the area of the wall and rate of global heat transmittance can be determined from an analysis of the components of the whole impedance to heat flow. The sum of the resistance is composed of the resistance to heat flow through the material, the interfacial resistance at the outside surface, and the interfacial resistance at the interior surfaces. While these interfacial resistances are determined mostly by factors over which the designer has little control, his or her main influence is on the permeability of heat, by varying the resistance to heat flow through the wall material. To decrease the heat transmission from one surface of a wall to the other, the thermal transfer should be cut as much as possible by both increasing the thickness of the wall and using materials with less thermal conductivity and thus providing higher resistance. Frequently, walls formed of several different materials are used to offer the required thermal and visual wall characteristics (Fathy, 1986).

Coefficient of thermal transmittance

In a hot arid environment, the coefficient of thermal transmittance must be around 1.1 kcal/ hm^2C^o for an external wall to have a suitable thermal durability (Table 2.6). According to Fathy (1986) it has been shown experimentally that mud brick is the most suitable material for achieving thermal comfort, in addition to being widely/generally available to all sectors of the population. This can be certified by the fact that whereas concrete has a thermal conductivity of 0.9, that of mud brick is only 0.34. Moreover, a mud brick wall is five times thicker than the prefabricated concrete panels, meaning that the thermal resistance of mud brick is 13 times greater than that of prefabricated concrete.

Table 2.6 Thicknesses of walls of different material and the coefficients of thermal transmittance.

Wall Material	Wall Thickness (in m)	Thermal Transmittance (in kcal/ hm^2C^o)
Hollow brick block	0.30	1.10
Double-wall brick with holes and 8-cm cavity	2 x 0.12	1.12
Brick wall with holes	0.38	1.03
Sand-lime brick	0.51	1.25
Hollow block sand-lime brick	0.51	1.16
Lime	0.51	1.10-1.35
Concrete	1.00	1.20

Source: (Fathy, 1986)

U-value

U-value is refers to the average heat flow through a surface which occurs due to conduction, convection, and radiation as a consequence of a temperature difference between the inside and outside. The higher the U-factor the greater the transfer of additional heat, which is thus lost from the surface at winter temperatures (Fathy, 1986). U-values can usually be read from the building documents, if available and can also be measured when insulation has been added to the building (Harris, 2012).

- The unit of U-value is W/m^2 degree C^o where:

Degree C^o (*degrees Celsius*) is the difference in temperature between the surface and the outside temperature.

W (watt) is the unit of power.

U-values for some common materials are given in Table 2.7.

- U-factors often range between a maximum of 1.3 for a normal aluminium frame with a single glazed window to a minimum of approximately 0.2 for a multi-layer, high efficiency window with low emissivity coating and isolated frames.
- A window with a U-value of 0.6 will lose double the amount of heat in a similar situation as one with a U-value of 0.3

Table 2.7 U-Values for everyday construction types.

<table>
<tr><th colspan="3">Type of construction</th><th>U-Value</th></tr>
<tr><td rowspan="7">Walls</td><td rowspan="3">Brick</td><td>Solid, un plastered 114mm</td><td>3.64</td></tr>
<tr><td>Plastered both sides</td><td>3.24</td></tr>
<tr><td>Inner skin lightweight concrete blocks 100mm</td><td>1.13</td></tr>
<tr><td rowspan="2">Concrete</td><td>Ordinary dense 152mm</td><td>3.58</td></tr>
<tr><td>Hollow blocks, 228mm, single skin, outside rendered</td><td>1.70</td></tr>
<tr><td rowspan="2">Stone</td><td>Medium porous 305mm</td><td>2.84</td></tr>
<tr><td>Medium porous 457mm</td><td>2.27</td></tr>
<tr><td rowspan="4">Roofs</td><td colspan="2">Reinforced concrete slab, 100mm, 3 layers bituminous felt</td><td>3.35</td></tr>
<tr><td colspan="2">As above with two 12mm fiber boards</td><td>1.25</td></tr>
<tr><td colspan="2">Timber boarding, 25mm on 178mm joists with 3 layers bituminous felt, plaster ceiling</td><td>1.82</td></tr>
<tr><td colspan="2">As above- with insulating slabs on boarding</td><td>1.25</td></tr>
</table>

Source: (Koenigsberger, Ingersoll, Mayhew, & Szokolay, Manual of Tropical Housing & Building, part 1: Climatic Design, 1974).

2.6.4.2 Transparent Surfaces (solar control glass)

Solar control glass reduces thermal gains to the room while retaining the view and light. This material is rarely used in residential buildings at present; however it has useful possibilities future use. Glazing materials with a low transferring coefficient are not recommended for houses, especially in the summer. (Santamouris, et al., 2001). Glazing materials exist in a variety of types:

Tinted glazing

Tinted glass has been used on a large scale in commercial buildings. It has only a small effect on sun glare; therefore it is recommended that blinds or other shading devices be used with this kind of glazing (Santamouris, et al., 2001). There are two main types of tinted glass:

Absorbing glass

Absorbing glass reduces the transmission of solar radiation through the window by reducing the direct transmission, and increasing outward emission after absorption (Lewis, Goulding, & Steemers, 1992).

Reflecting glass

This form of glass is made by coating the glass with a thin layer of extremely reflective metal oxide on the outside of the pane. This can lead to problems of durability; the film has to be located on either the inner face of the outer layer of the glass or the outer face of the inner layer. If the reflective film is located on the inner glazing, the design of a double glazed unit has to ensure that the air in the gap does not get heated up and cause loss of seal (Lewis, Goulding, & Steemers, 1992).

Reflecting glass is somewhat better than absorbing glass at avoiding incoming solar gain because the latter heats up more while the sun is on it, and some of this heat might reach the inside of the building. In certain cases however, reflective glass could lead to unwelcome solar glare for pedestrians and road users on the outside (Littlefair P. J., 1999).

Low emissivity glazing (Heat mirror)

Low emissivity glazing has only a slight effect on solar heat gain, though it is excellent at keeping heat in and therefore ideal where heat loss is significant. This style of glazing admits a considerably larger amount of daylight than conventional tinted glasses. However, noble metal covered, heat mirror and low emissivity glazing are also available. The thermal properties of these types of glass are able to be modified to guarantee a good solar control (Littlefair P. J., 1999).

Window films

Window films are suggested for existing windows which receive excessive solar heat gain and where losses of daylight are not significant. Compared with painted glazing, the chief benefit of window films is that they can be installed in the majority of already existing buildings and are comparatively less expensive. They can be cleaned similarly to normal glazing, but it is important to avoid the film being roughened (Littlefair P. J., 1999).

Other glazing types

A wide choice of other glazing types is available, including diffusing glazing, prismatic glazing, “smart glazing” and fritted glazing, but they are not often used in residential buildings (Littlefair P. J., 1999):

1. Fritted glass

One of the recently developed glasses in solar control gain is fritted glass. The fritting procedure is the deposition and vitrifying of opaque ceramic dots (circular patches), generally between 1 and 10 mm in diameter, on to the surface of glass, occupying between 30% and 70% of the surface. The dots are more often white, and therefore reflected away an equivalent percentage of the radiation. The shading performance of this style of glass is similar to fixed screens. They interfere with vision, although due to the tiny size of the dots, they appear to be cloudy and diffuse rather than being seen as visible structures (Baker & Steemers, 2002).

2. Diffusing glazing

Diffusing glazing (frequently translucent plastics) spread sunlight falling on them. They stop patches of direct sun reaching occupants but they also stop the outward view. As a result, they are mostly used in roof lights or high level glazing, or anywhere continuous privacy is required (Littlefair P. J., 1999).

3. Prismatic glazing

This kind of glass consists of a collection of long (usually triangular) prisms, which reflect and refract. They can redirect external sunlight onto the ceiling as well as stop it overall while admitting diffuse light. If installed below eye level, prismatic glazing spoils the view and can be a source of glare (Littlefair P. J., 1996).

4. Smart glazing

Smart glazing's are able to control solar gain when necessary but also admit daylight and useful solar heat in winter. They include:

1. Electro chromic and liquid crystal glazing which darken when an electric current is applied.
2. Photo chromic glass, which darkens under sunlight.
3. Thermal chromic glass which turns milky under heat.

2.7 Solar gain control strategies in hot arid regions

In order to design a residential building which has low energy consumption, particularly in hot arid regions, the architect has to deal with the overall geometrical factors related to the building's height in relation to the street dimensions, facade orientation, form and proportions of the building, as follows:

2.7.1 Zoning and internal orientation

A residential building is able to be made more energy efficient basically by relating its zones to sun movement. Furthermore, spaces that require cooling have to be located on northern facades while spaces that require day lighting must be located near to the walls or roof of the house. A building outstretched along the east-west axis exposes the longer south side to highest heat gain during winter months, and the shorter east and west elevation to maximum heat gain in summer time, as shown in Figure 2.38. Consequently, a building elongated along that direction is considered to be the largely efficient shape in all climates for minimizing heating requirements in winter and cooling in summer (Olgyay, 1963).

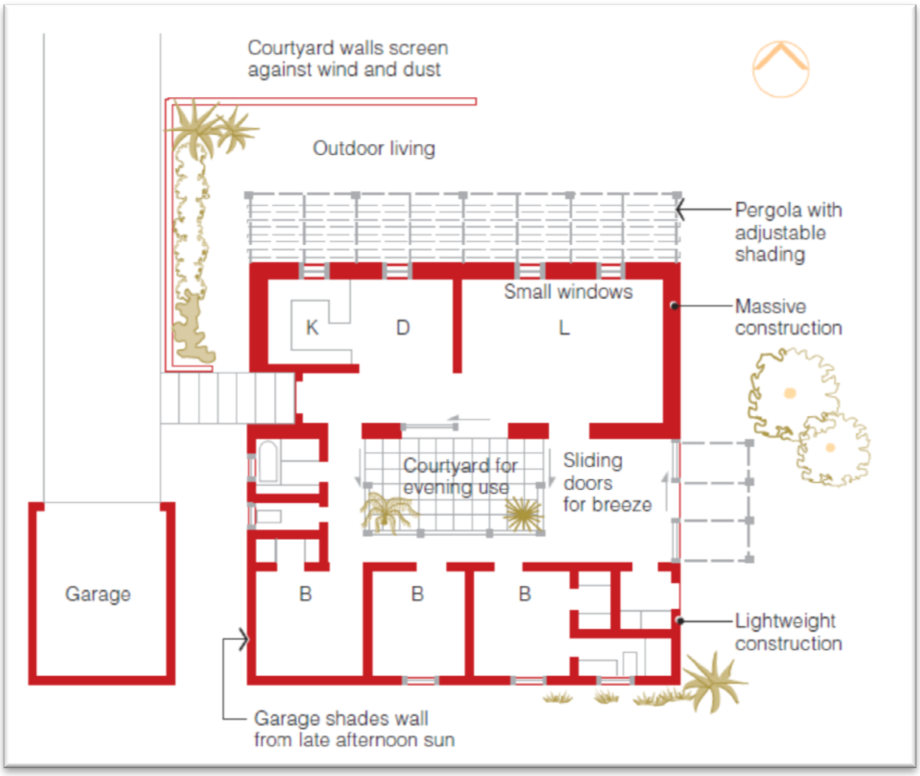

Figure 2.38 Internal orientation for houses in hot arid climate. Source: Cement Concrete & Aggregates, 2007

In addition, the behaviour of occupants influences the effectiveness of the design in use and thus user demands have to be taken into account. User patterns and the time of occupation might also influence the design of individual rooms. If a bedroom is not occupied during the day, the indoor climate during daytime is of no interest and the design must be optimised for night comfort (Rosenlund, 2000).

2.7.1.1 Design of openings

The design of openings in hot dry regions is governed by two requirements (Koenigsberger, Ingersoll, Mayhew, & Szokolay, 1974):

1. For the duration of the day, the design of windows should be as small as possible and apertures positioned high on the walls will be more desirable.
2. For the duration of the night, the windows should be large enough to offer sufficient ventilation for the dissipation of heat emitted by the walls and roof.

Solar heat gain can be reduced roughly in proportion to the reduction in the window area. Researchers have recommended that to satisfy light requirements in hot dry regions a glass area must be 1/16 of the floor area of a room (Saini, 1980). Also, setting the glazing back from the outside, in order to keep it shaded at most times is a traditional design strategy that remains very successful (Littlefair P. J., 1999).

In a day lit building, a window acts as a visual rest centre, and the extension of view, which the window creates, requires a change of focus, as well as an adaptation. Generally, the area of the window determines the amount of sunlight that enters the room, but the shape and position of the window controls the spread (Phillips, 1964).

The appropriate size and shape of openings should also relate to the activity carried out in the same space. Tall windows are preferred for their good day-lighting properties. In contrast, continuous ribbon glazing with reduced window head height causes problems of poor daylight distribution. The shape itself is not very important, except when it influences the zone around the window wall. The best solution that can meet both needs is the use of large openings with massive shutters that must have a thermal capacity approaching that of the wall or a high thermal resistance. For example, the "mashrabiya" (classical projecting oriel windows) shown in Figure 2.39 soften the light and minimize direct high angle sun diffusion (Baker & Steemers, 2002). If these are kept closed for the period of the day, the heat flow is retarded, and if opened at night, the heat dissipation is not blocked, as shown in Figure 2.40.

Figure 2.39 The mashrabiya restored Ottoman residential building near Khan al-Khalili, Cairo. Source: (Allegretti, 2012)

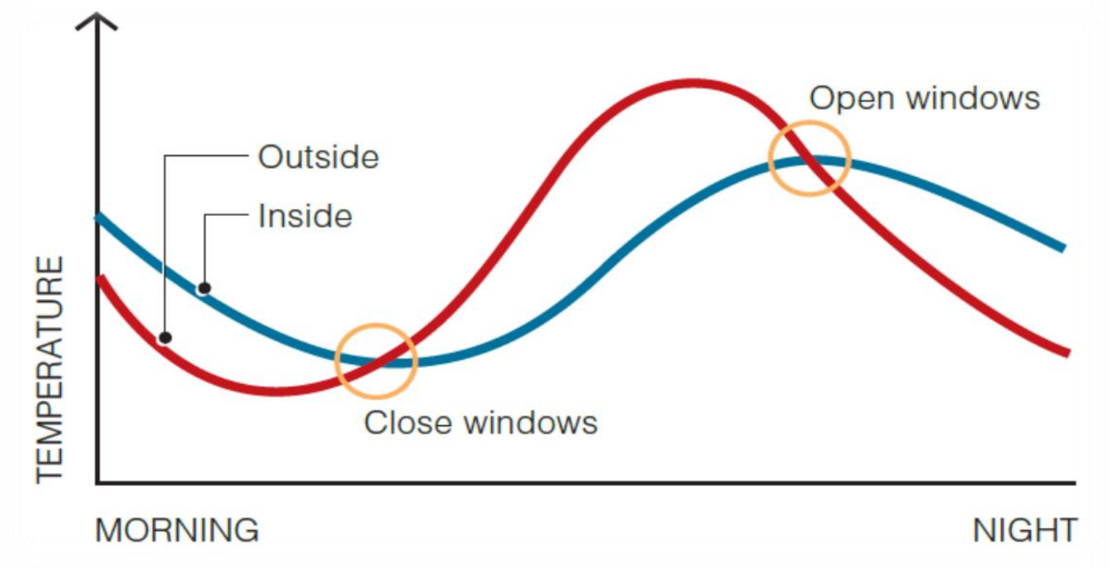

Figure 2.40 Control of ventilation in a hot arid climate. Source: (Rix, 2007)

There are five functions for mashrabiya. Different patterns have been developed to accommodate a variety of conditions, each of which may need emphasis on one or more these functions.

1. Controlling the passage of light.
2. Controlling the air flow.
3. Lowering the temperature of the air that is currently in the room.
4. Increasing the humidity of the current air.
5. Ensuring privacy.

Every mashrabiya is specially designed to meet quite a few or all of these functions. In the design, the size of the gaps and the diameter of the balusters are adjusted to meet desired purposes. Several patterns have their own names to identify them (Fathy, 1986).

However, the designer has also to consider the living habits of the occupants. It could happen that shutters are left open during the day and closed during the night, thus producing the opposite of the desired effect (Koenigsberger, Ingersoll, Mayhew, & Szokolay, 1974). Generally speaking, people expect to control the shading themselves in their homes, and tend to resent automatic shading (Littlefair P. J., 1999).

2.7.1.2 Design of the roof

In designing a roof, the most important consideration is the reflectivity. Shade can be achieved by using a double roof with a layer of air between or by covering the roof surface with hollow bricks. Insulating material such as fibreglass and lightweight blocks are often used. Using the specific materials required for such a solution is likely to increase the cost of the building beyond the means of most of the population in hot arid zones. However, as explained in Chapter 2, growing a roof garden might significantly reduce the roof temperature and it can also be used by the residents as a recreational space. The soil is an excellent heat insulator, and moreover plants can offer shade. Plant life also transpires and cools the air in contact (Fathy, 1986).

The ceiling height is a main issue linked to roof form. Traditional buildings in hot arid climates frequently have high rooms, particularly those with domes or vaults, which add to the room's height, and thus also to the volume. Givoni (1976) found that in a hot climate, a reduction of the height from 3.6m to 2.4m corresponds to about 2% increase in the general cooling needs of the body.

In hot arid countries, as the air temperature drops significantly during the night-time, the inhabitants have organized the architecture of the roof into open galleries and lightweight roof covers. This roof sheeting has a dual function of shading the roof just during the daylight hours of the day and provides a comfortable living temperature at night. The form of the roof is also of major significance in a sunny climate. Flat roofs receive continual solar radiation during the day, at a rate increasing in the early morning and decreasing in the late afternoon, because of the changes in solar intensity as well as the angle of the sun. Compared to a flat structure, a pitched or arching roof has several benefits. The main significant benefit is that the whole surface space of the roof is increased, resulting in the solar radiation being spread over a larger area, which cuts down the average temperature. Secondly, for the majority of the day, the sun shades part of the roof, at which point it can act as a radiator, absorbing heat from the sunlit fraction of the roof as well as the internal air, and transmitting it to the cooler air outside in the shaded surfaces. This last effect is mostly effective for roofs arched in the form of a half cylinder and those arched in the form of a hemisphere, since some part of the roof is always shaded, except at midday when the sun is directly overhead (Fathy, 1986).

2.8 Summary and conclusions

Human thermal comfort depends on many factors: occupant factors such as the age, gender, culture, activity, clothing of the individual, and environmental factors such as air temperature, humidity and air movement. A number of comfort indicators are used to assess the impact of a number of climatic factors and also individual comfort zones on human comfort.

The results indicate that the higher the urban density in a particular area, the less its direct solar access through the summer. High buildings are more easily shaded than extended ones for the reason that summer irradiation is most concentrated on roofs. Construction of a double roof is the most effective process of shading the main roof of a building, but is considered to be expensive.

Overshadowing can be minimized by adding sufficient spacing, making adjustments to the grouping of houses, or by a small shift in orientation. Thus, obstruction of light is influence by height and the distance from the affected elevation. It is capable of reducing the daylight distribution in a building and might cause overshadowing. It has been shown that courtyards are considered to be the most superior form of exterior space in a hot arid climate. Colonnades can also be used to enhance solar gain control in private courtyards.

Furthermore, a south-north house provides better shading potential throughout the year compared with other orientations, while, east-west roads are perfectly orientated for solar access in winter and shading in summer. Northern and southern oriented slopes are the most shaded in summer.
The inverted pyramidal shaped structure allows partial self-protection for solar radiation during a requisite period.

External shading devices are more efficient than interior ones at preventing overheating, but carry penalties of cost and lack of control. Interior devices have lower effects on reducing heat gain in the room. Compared to internal devices, mid-pane devices provide better protection from the sun’s heat, take a longer time to get dirty and do not take up space inside the building.

It has been also established that using vegetation is the greatest solar gain control device and can both shade the house in summer and allow solar gain in the winter.
In hot arid weather, the coefficient of transmittance must be approximately 1.1 $Kcal/hm^2C^o$ for an external wall to contain a suitable thermal resistance.

It has been pointed out those types of solar control glasses are not often used in current residential buildings, but have good potential for the future. They decrease thermal gains to the room as well as retaining the view and light. Understanding of all these factors will be applied in the case study and analysis.

3 Chapter 3 Solar gain control design and evaluation tools

3.1 Introduction

Before the advent of current mechanical means for maintaining thermal comfort, people who lived in hot arid regions were forced to find ways to cool their homes using simple natural sources of energy and the physical phenomena around them. In general, these solutions have been found to be more in harmony with the human physiological functions than current means, such as electrically powered arid region coolers and air conditioners. This situation remains true for the majority of people in the industrially developing countries, where the conventional energy sources of the industrialized world are not readily available at affordable prices. There is a clear need to further develop traditional systems based on natural resources. Before proposing or inventing new mechanical devices, traditional solutions drawn from vernacular architecture must be considered, which can then be adapted or modified and developed to meet modern requirements. (Fathy, 1986). This procedure needs to be based on recent developments in the physical and human sciences, as well as the fields of passive cooling and, principally, solar gain control.

There are several available design tools to help the architect in the solar control design of a building. They range from moderately easy paper-based evaluation procedures to advanced computer simulations. The majority of solar control design tools are based on numerical or experiential relations. However, the user does not necessarily have to recognize these complex formulae to be able to use the tool. With the help of regulation documentation or training, the designer can gain the necessary skills and information quite simply.

The procedure of selecting the most suitable tool can be a difficult one (Ward & Rofchaei, 1995).The design tool for solar control chosen by the designer should be appropriate to the task at hand. For the early design phase, design tools need to be quick and interactive in order to allow the evaluation of alternatives without a great investment of time and effort. In some cases, the important information is not quantifiable, but is qualitative or perceptual. Alternatives can be considered at the design stage and the best solution can be chosen depending on the issue to be studied, which is analysed at the stage of the design process.

Since the 1960's, the use of simulation tools and computer modelling in building construction has increased greatly. However, despite over 50 years of progress, architects are still sceptical as to whether these types of tools have a role in the design procedure. The fundamental question still remains; "Does the use of computer based tools actually make better building?" The real challenge is to use these tools in the early stages of design, where an additional informed analysis of possible alternatives can yield the most advantage and the maximum cost savings, both in the economic and environmental areas.

3.2 Designing residential buildings in hot arid regions

In designing and planning residential buildings for the hot arid zones, two of the major problems confronting the architect are to guarantee protection against heat and afford adequate cooling. The world's major source of light and heat is the sun, which also creates the subsidiary climatic elements of wind and humidity that influence physiological comfort. As explained in the previous chapter, the arrangement of structures, orientations, and planning in different areas generate a particular microclimate for every location. In addition to these factors, the building materials, surface textures and colour of uncovered surfaces of the buildings, and the design of open spaces, such as streets, courtyards, gardens, and squares should also be taken into account. There is little doubt that particular configurations make better climates than others. For every site, there are optimal arrangements in space that the designer must seek and use as a standard of reference in the process of deciding upon a particular design (Fathy, 1986).

In the past, people in hot arid regions built their houses according to their real needs while making optimal use of the available local building materials. For many generations they depended on accumulated wisdom for deciding on the orientation and shaping their cities and homes. (Koenigsberger, Ingersoll, Mayhew, & Szokolay, 1974).

3.3 Thermal considerations for residential building types in hot-arid climates

Different residential building types show different thermal performance characteristics in a hot and dry climate. Their effectiveness on comfort and solar gain control has been comprehensively discussed by Givoni (1998).

3.3.1 Single family detached houses

A single-family detached house has the peak envelope facade area among the different building types. When they are built around an interior courtyard, the envelope surface region is increased. The roof is the major surface of the structure which is exposed to the climatic elements, such as solar emission, during the day in summer. Consequently, this building type could produce the maximum internal discomfort. However, the roof is also a part of the structure which can be insulated to a higher level of thermal resistance than the walls, and such insulation reduces, comparatively, the solar gain of the whole building.

Detached houses allow the occupants to use the ground surrounding the building for a variety of outdoor activities. This point is specifically important for families with many children and low income, who generally can afford only extremely small residences.
In addition, these houses can best use nearby vegetation for solar gain control. Consequently, when the geography or other matters do not allow the best possible orientation of the building, a detached house might be the most suitable type in a hot environment regardless of their huge surface area envelope.

3.3.2 Town houses (Row houses)

Town houses and dwelling forming a row of continuous units with shared walls. Thus, the total area of wall exposed is less than in single-family houses with the same number of floors.

The exception is the end unit dwelling, which has basically two exterior orientations. However, this type of housing building is more sensitive than detached houses to orientation, with respect to the sun and the direction of wind. In a hot, dry environment a north-south orientation for the exterior walls will reduce the exposure of the town house to the sun in the summer and get the most out of its possibility for solar heating in the winter. The situation may be more complicated with regard to orientation for ventilation, as it is the case in many hot, dry regions that the prevailing wind direction is from the west. In this situation long walls should be positioned to the north-west and south-east, with details of the design that “catch” the western wind by allowing it to enter from the north-west in the north–west wall and with an outlet in the south-east wall, can be the best possible solution for town houses.

Therefore, town houses, if oriented and designed appropriately, are better thermally adapted to the environment in hot-dry regions than single family detached houses. However, with an inappropriate design, they may be less comfortable and require additional solar gain control design tools.

3.4 Forms of solar control design tools

3.4.1 Simplified manual tools

Manual tools are more useful for designers who are more familiar with drawings then calculations. Following an easy process, they can obtain significant data at the early stages of design. This type of equipment helps in the design of solar control devices and in the assessment of their performance. It can also be used to estimate the extent of shade caused by neighbouring buildings and nearby vegetation.

Most manual tools assume shading from the direct solar radiation and disregard the diffuse and reflected radiation. Some of the tools give a graphical interface to view objects as well as the shadows. Manual tools which are of use in solar control design generally fall into two groups as follows.

- Tools for predicting solar geometry
- Tools for predicting the performance of shading devices

3.4.2 Tools for predicting solar geometry

The geometry of the sun path and its relation to the earth is specifically known, which enables the designer to forecast solar altitude and azimuth. The altitude and azimuth angles changes from hour to hour and season to season according to the sun path. They can be sketched on a sun path diagram for the complete year (day by day). Sun path diagrams are the most popular design tool in this group with architects, due to their straight forwardness and ease of use (Baker & Steemers, 2002).

Sun path diagrams

Shadows move with a similar accuracy to the sun, and the varying effect of a shadow on the ground or on a wall has been used for time measurements for over 3000 years (Holmes, 1975). They have two major uses (Baker & Steemers, 2002)

- To assess the shading impact of surrounding buildings and landscape characteristics.
- To predict the penetration of sunlight into a building (in various cases, for

verification of the performance of shading devices).

Two basic steps in designing shading devices using sun path diagrams have been identified (Szokolay S. V., 1996) and (Koenigsberger, Ingersoll, Mayhew, & Szokolay, 1974):

Definition of the shading time and specification of shadow angles

Before designing any solar management device, it is significant to make a decision when shading is requisite, at what month or season of the year and between what hours of the day. Moreover, it is important to think about the building type, existing thermal mass and inner heat gains.

Shading time can be defined in three ways:

- In terms of air temperature alone.
- In terms of air temperature, integrated air temperature and humidity and possibly air movement.
- In terms of solar-air temperature, individually for each surface of different orientation.

The first one is the easier. Using any forms of comfort indices (discussed earlier in 1.2.3), shading will be needed whenever the outdoor temperature is higher the than comfort zone. At every hour temperature calculator is then used. Otherwise, a set of coordinates, with month lines horizontally and hour lines vertically, are linked by a curve representing, identical temperatures on an isopleth.

The overheat time is then transferred to a solar chart, in order to transfer it to a cylindrical or a stereographic sun path graph.

3.4.3 Physical modelling

Solar control design options can be studied through physical modelling by changing one variable at a time, such as window size, placement or orientation. The most satisfactory solution can be found, and design decisions based on the quantitative and qualitative results obtained can affect the building design (Ander, 2003). A very large scale model of a single window with part of the room it belongs to can be the most useful aid for evaluating the performance of a shading device. Designers can also use it in selecting one of several potential devices. With movable parts and separate pieces, it could be used as a design tool to determine the best form and location of a device (Koenigsberger, Ingersoll, Mayhew, & Szokolay, 1974).

Used in pairs, models can be used for visual comparison of alternative design proposals. Physical models can also be used to create quantitative measurements; however, for accurate results, calibrated sensors and a well-defined "outdoor" bright environment (such as artificial sky) must be provided. (McNicholl & Lewis, 1994).
Physical modelling includes a number of devices that simulate the sun-building relationship either with the real sun or a sun simulator. These are described below.

3.4.3.1 The use of the sun

If the actual sun is used, the model must be sloping and rotated to represent different times of day and seasons. The size of the model must be carefully considered to be simply sloping and rotated, and the whole thing on it must be securely fixed (Littlefair, et al., 2000).

The sundial

Figure 3.26 shows the sundial, which is an extremely easy and cheap tool, which is attached to the model (folded and pasted inside a matchbox). A14 mm elevated stick is locate at the 'N' point of the sun-dial and oriented to the north point of the model. The model is turned and tilted until the tip of the shadow of the stick is at the specified date and hour. Any light source can be used with the sundial, although best results are obtained with real sunlight (Koenigsberger, Ingersoll, Mayhew, & Szokolay, 1974).

Basically, the sundial has a straightforward edge parallel to the polar axis of the earth, so that the location of its shadow depends only on the orientation of the earth and not on the seasonal changes in the elevation of the sun's path as shown in Figure 3.27. The plan of the sundial can be in any orientation, with the graduations of the hour scale spaced accordingly. The shadow will always be due north of the style at midday, and for other times, the graduations might be determined by experiment with a reliable watch or calculation (Holmes, 1975).

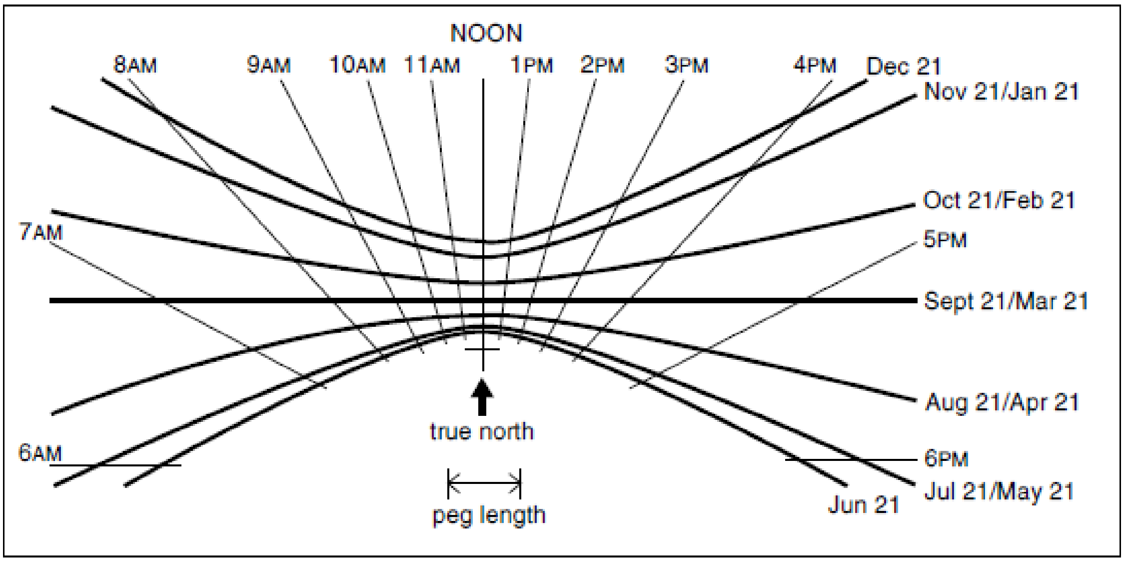

Figure 3.1 The sun-dial at 32 degrees north. Source: (Lam, 1986)

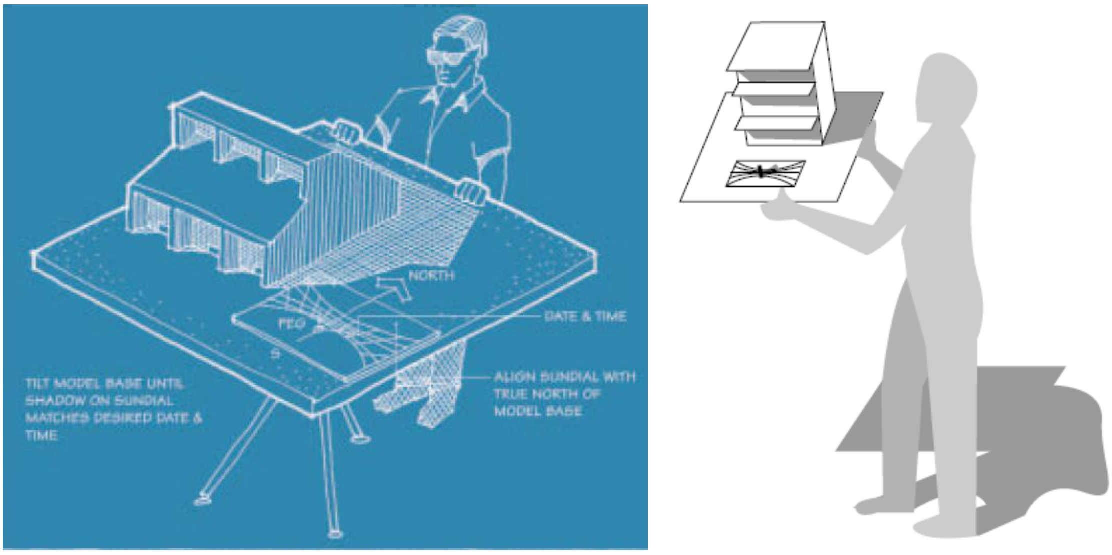

Figure 3.2 Physical model study with a sun dial. Source*:* (Nagy, Hayter, Larson, Torcellini, & Geet, 2002).

The heliodon or "sun machine ".

The heliodon, shown in Figure 3.28 has a tilted and rotated model-table for latitude and hour adjustments, respectively. It can be used in the actual sun or with the help of a light sliding up and down on a vertical rail at different distances away for time and year modification. Even though, it is an easy and cheap tool, it has some disadvantages (Koenigsberger, Ingersoll, Mayhew, & Szokolay, 1974).

1. It has a quite small table, which can be too small for some models.
2. The model used with the heliodon must be fixed, as it will be tilted.
3. It is not easy to visualize the relative situation of the sun and the building.

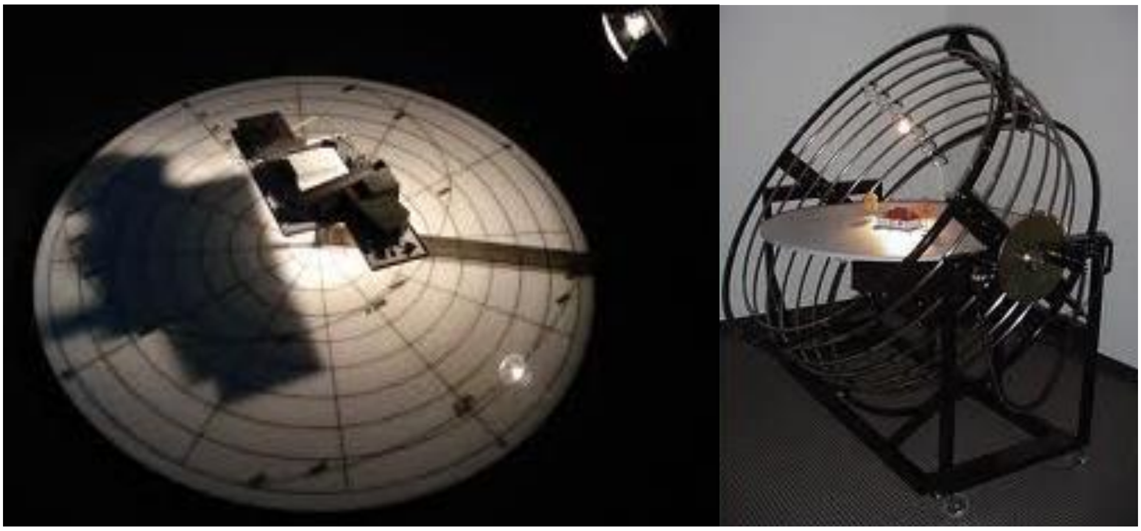

Figure 3.3 The Heliodon (Vogel, 2011).

3.4.4 Computer-based tools

Computer software used to design and evaluate solar control in buildings range widely in nature, complexity and cost. Usually, the use of a computer tool in solar control design has several advantages:

1. It can be used for any geographical location and any building plan.
2. Using such a tool is easy, accurate and fast, therefore it is possible to evaluate and design several alternatives for window orientation and geometry.
3. It is possible to use it for educational purposes in order to understand the various relations between the sun's movements, building geometry, and performance.

When considering computer modelling for solar control studies, it is important to know (Littlefair, et al., 2000):

- What obstructions the program can model and how easy it is to input them;
- If complex external obstructions (or irregular ones) require a lot of extra computer memory or result in long run times;
- Whether sunlight can be modelled and the nature of algorithms used.

3.4.4.1 Forms of computer-based tools

These tools can be characterized into three main categories, as follows:

Tools for the prediction of solar position and geometry

Computer based tools in this category are not considered as complete solar control design tools. However, they can be used as a primary stage in order to set the required shading period. They have the following main characteristics:

1. They are generally user-friendly programs, and do not require any high level of

expertise, just basic understanding of solar geometry.

2. They are used to determine the most favourable range of orientations for passive solar cooling, showing hours when shading is required.
3. Their output is usually in the form of tabulated data or two dimensional images of the site in plan set against a sun path diagram for the relevant latitude. Some programs include a thermal comfort psychometrics analysis.

The following list summarizes some of the most recent and frequently used tools in this area, and their characteristics and output:

CLIMATE 1 Developed by institute Fuer Geographie, University of Flensburg, Germany (2005).

This is a worldwide climate data base atlas, which consists of a data base that holds more than 1200 station data sets. Station data include sunshine hours, so no input is required, just the selection of a region and a station on the map, moreover, the sun charts are given for each station selected.

IWEC Developed by ASHRAE, Atlanta, Georgia, USA (2006).

This includes weather data (supplemented by solar radiations estimated on an hourly basis from the earth-sun geometry) and is suitable for use with building energy simulation programs. To use it the appropriate weather data file is selected by location name. The **IWEC** files contain 8760 hourly records.

SUN ANGLE Developed by Sustainable by Design, Washington, USA (2002).

This program calculates solar angles based on location, date, and time. It provides location, data including time and zone declination, local solar time, hour angle, solar altitudes, solar azimuth, and time of sunrise and sunset.

SUN-CHART Developed by Optical Physics Technologies, Idaho, USA (1997).

This program calculates sun charts, performs shading calculations and plots shading diagrams onto cylindrical sun charts, simply by entering the latitude. Some calculations also require the longitude. Shading calculations require the input of building geometry values t. Most of the calculation results are represented as graphical sun charts.

SUN PATH, which was developed by Sustainable by Design, USA (2002) displays the path of the sun in the sky for any date and location and provides a graphical display of the sun path in the sky. Text files consist of sun angle data and the specific sun angles.

SUNPOSITION developed by Sustainable by Design Washington, USA (2002)
This calculates the sun angles for a given location when the user inputs the geographical location, the frequency of the data desired and the required output format, which are in the form of text files consisting of sun angle data and the specific sun angles.

WEATHER TOOL developed by the Centre for Research in the Built Environment, Cardiff University, UK (2004).

This tool displays a wide range of sun path diagrams and can determine optimum orientation for specific building design criteria. Weather Tool provides 3D graphics, as well as a climate summary, graphs, and sun path diagrams for hourly, weekly, and monthly time-frames.

Tools for the design and evaluation of shade caused by obstructions

Computer-based tools of this category are more advanced than those in the first category in their ability to assist in shading design and evaluation. They have the following main characteristics:

- The level of required expertise is the average level of PC computer skill, together with considerable understanding of basic solar radiation concepts.
- They could also be used for design of simple shading devices (such as overhangs).
- A number of programs in this category include a complete CAD module, so that surrounding buildings and their effects may be plotted.

3.5 General comparisons between solar gain control design tools

The use of different categories of solar gain control design tools does not lead to a unique final design. Once the necessary shadow angles and overheated period have been established, the design of the actual form and geometry of the device can be left to the designer's preference. Therefore, the freedom of the architect is not limited by the capability of the design tool (within the overheated period), as previously thought. However in order to obtain relatively accurate results from any design tool, the exact design data must be inputted. For example, the depth of the wall where the aperture is situated minimizes the dimensions of the right and left side extension of an overhang. Ignoring the effect of this depth by either the manual tool or the computer tool could maximize the side extension dimensions of the shading device.

In general, the success of any design tool is only proven when many designers and architects apply the tool successfully in their design. The emphasis should be on using the proper category of design tool for the solar gain control task and learning while applying it. Comparisons between the three categories of design tools fall broadly into the following points.

3.5.1 Degree of sophistication

The comparison of the degree of sophistication is based on the capacity of the tool in the following areas.

3.5.1.1 Defining the shading period

Generally, the shading time is described more accurately in the manual tool using specified hours in different months. The physical tool imports the same data from the manual tool. Although in the computer-tool, the shading time can be set by exact hours, the user must set the required period (by days and months) himself.

The use of some manual tools, like the Mahoney tables, to define the shading period is not always necessary as this data is sometimes already available for major cities and settlements. Computerized Mahoney tables have been in use since 1974. The table establishes the preferred comfort range, carries out a diagnosis and translates this into recommended specifications very quickly.

3.5.1.2 Defining the geometry of the aperture

The manual tool does not consider any shadow made by the depth of the wall where the aperture is situated, although this depth might contribute to minimizing the dimensions of the designed shading device.

Commonly, computer software programs are restricted to a simple geometrical configuration of apertures. Due to this restriction, the shading of tilted apertures cannot be determined. They currently work only for vertical walls and simple overhangs. Also, shadows from opposite or tilted surfaces, building parts and the surrounding landscape cannot be presented. Manual calculations are also unable to help in designing shading devices for a non-vertical aperture. Only physical tools, in this case, have the capacity needed for designing shading devices for any complex building shape, including curved walls, angle of inclination or form of aperture: as many residential buildings designed today are not the simple box or cube, a physical tool may be the most efficient design tool in this case.

3.5.1.3 Visualization capability

Usually, architects and designers tend to be sophisticated at grasping complex information visually, rather than in the form of numbers or text. Physical and computer-based tools have more potential than manual tools in this area. They help designers to see the differences in performance between any two successive designs and to understand whether the building's performance is becoming better or worse. These tools also provide a more realistic design environment which is more likely to evoke responses similar to those of real buildings. In addition, computer-based tools add the new dimensions of time and motion to the design process. The value of simulation lies in the translation of a set angle, elevation and number into a picture of the proposed aperture in an understandable context; so that shading information can be more clearly presented before the residential building is built.

3.5.2 Speed and accuracy

Much of the potential for error in using solar control design tools comes from the architect's lack of familiarity with a particular tool. A user, who is proficient with a simple manual tool and has a little understanding of the mechanics of sun position and sun-path diagrams, will usually get better results than an inexperienced user running a highly sophisticated computer based tool.

In manual calculation tools, the accuracy of prediction tends to increase with the increased complexity of calculations. Also, once the use of manual tools is understood, re-use at a later date may only require a brief review of the designer documentation.

The disadvantage of designing solar control devices using the sun with **the Heliodon** is that it is not a fixed light source. Therefore, if the model is left in one position for a while, the sun angles change as the sun moves across the sky. The time needed to determine the dimensions of a shading device must be minimized to avoid differences in shadow position. Moreover, sometimes architects get carried away and update their models to an extent that cannot be justified by the shading problem that remains to be resolved. It is important to remember why the model exists. The recommended procedure when great accuracy is desired is to build first a small scale model of the building. When the general shading issue at that scale is resolved, a larger scale model of a critical detail such as a typical window can be built. If the same window detail is used on more than one elevation, then the same model can be turned on the Heliodon to simulate different exposures.

The computer-based tool still remains the fastest and most accurate tool among the three categories of design tools, the aim of any computer effort. However some data, such as the shading period must be known before using the software.

3.5.3 Limitations

In cases of physical tools studies, tilting a model to simulate different months and hours may cause distorted results, according to the season where the test takes place. When the measurements are made in the winter and the model is tilted downward to simulate a higher summer sun the amount of error increases the more the model is tilted; conducting the measurement on a rooftop or in the summer when the sun is high can minimize this. In this case, the model is tilted upward to simulate the low winter sun.
With a physical model, it is hard to make it large enough to view inside, whereas the computer model makes it easy to move through a space. However, the computer model does not yet effectively represent other conditions, for example gravity, as physical models do.

3.5.4 Use and cost

Physical modelling has several shortcomings in this area. These include cost of materials, manpower and instruments, in addition to the problems of preparing and constructing the models. In addition, once they have been constructed, it is difficult to modify physical models in response to changes in design feature. Therefore scale modelling is not considered as a cheap and fast design tool (see Figure 3.37).

Although building simulation can add substantial value to a building's design to bring about solar control, it must be borne in mind that it may not be right for every residential project. Sometimes, the time and cost of developing a good model outweigh the benefits that it may potentially provide. In general, designers must not assume that computer-based tools and building simulation are the immediate solution whenever there is a shading design problem. Instead, they need to carefully consider whether building computer-based tools is necessarily the best way to solve this problem.

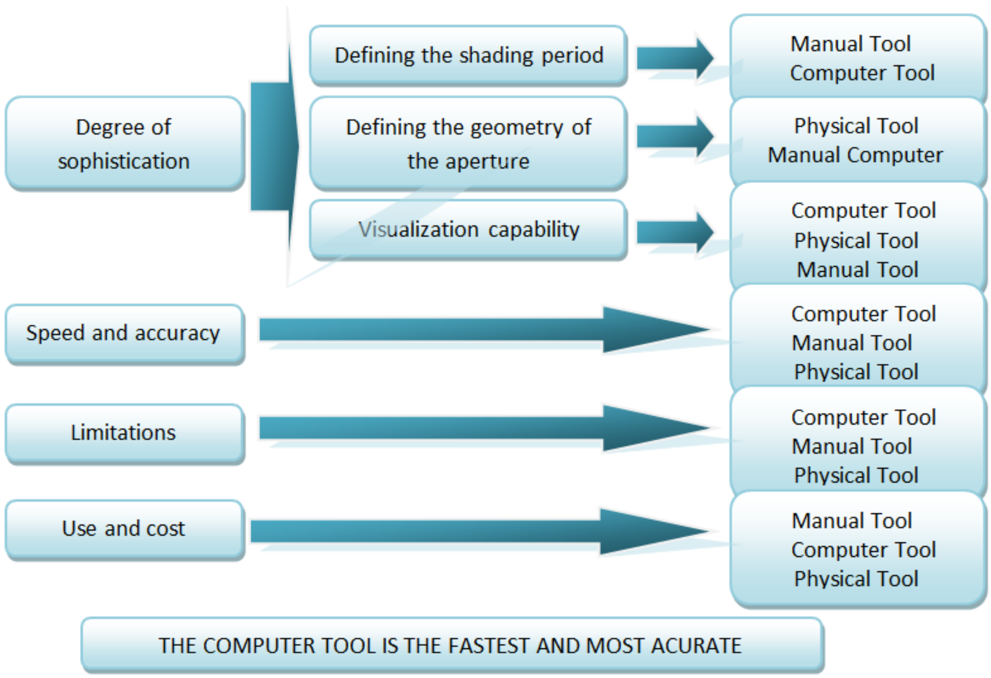

Figure 3.4 General comparisons between solar gain control design tools. ***Source: the researcher***

3.6 Description of the chosen design tool

It is concluded that the computer tool is the fastest and most accurate tool among the three categories of solar control design tools studied earlier. For this research, the solar gain control performance of the case study residential building will be mainly evaluated using the Solar Tool program Ecotect analysis.

3.6.1 Advantages:

1. It combines the advantages of the three computer based tools categories discussed earlier. It also handles simple shading models design to full scale cityscape planning.
2. It determines the extent of solar penetration into buildings as well as overshadowing. It sizes and positions shading devices (any number of horizontal, vertical and detached shades) or the most appropriate means of shading a window. The user can select any date, time or location, seeing immediately the resulting shadows.
3. It can calculate solar availability over the spaces around buildings and in highly overshadowed urban sites: this allows for the optimum location of vegetation and garden layouts around buildings. The amount of solar radiation falling on any object can be quickly calculated, along with shading and reflection percentages.

3.6.2 Disadvantages:

1. The required shading period must be known before using the software.
2. The forms of tilted and curved apertures and walls cannot be determined.
3. Ecotect imports files from Autodesk Revit architecture software DFX files.

3.7 Summary and conclusion

It has been established from the literature reviewed in this section that a building elongated along the east-west axis is considered to be the most efficient shape in all climates for minimizing heating requirements in winter and cooling in summer.

A glass area 1/16 of the floor area of a room should be satisfactory for the light requirements in hot-dry regions.

In relation to the roof design and materials, it has been shown that a roof garden reduces the temperature of the roof and that shade can also be achieved by using a double roof with a layer of air between or by covering the roof surface with hollow bricks. Insulating materials such as fibreglass and light weight blocks are often used. Pitching or arching the roof has several advantages over a flat structure.

Detached single family houses may be the most appropriate type in hot dry regions, despite their larger envelope surface area. Town houses, if properly designed and oriented are, are better thermally adapted to the climate in hot-dry regions than single family detached houses. Double loaded corridor apartment buildings are not suitable in hot dry climates if they are so oriented that the corridor is open in summer and is located on the leeward side of the building. Two units per stair case have reduced heat gain in summer and heat loss in winter. However such buildings are very sensitive to orientation in their thermal performance. Three or more units per staircase are not recommended for hot-dry regions.

Manual tools provide the minimum acceptable level of solar gain control design and they are the most popular design tool among architects, due to their simplicity and ease of use.

The oldest technique in shading design is the use of a physical model. It can be used for evaluating the performance of shading devices and to determine the best geometry and position of the device.

Computer based, tools, used to design and evaluate solar gain control, can simulate the sun’s movement around the building, design and evaluate shading caused by obstructions as well as shading devices. They are considered to be the fastest and most accurate tool among the three categories of design tools. Solar tool is effective and will be used in this research. Little research has been done for hot dry climate.

4 Chapter 4 Methodology

4.1 Equipment that has been used to collect data

4.1.1 Enternal temperature equipment

The wireless Temperature Logger System consists of a Temperature Logger Software application, a USB receiver module and 18 sensors, each including a transmitter and connected to the system at the same time Figure 4.1. A USB cable connects the receiver to the computer system running the temperature logger application. The temperature logger application at the computer displays all temperature data, which have been transferred by the sensors to the USB-receiver. Temperature sensors continuously registrant temperature and report it every 45 seconds. Each sensor reports the data and time stamp for the most recent measurement data set Figure 4.2.

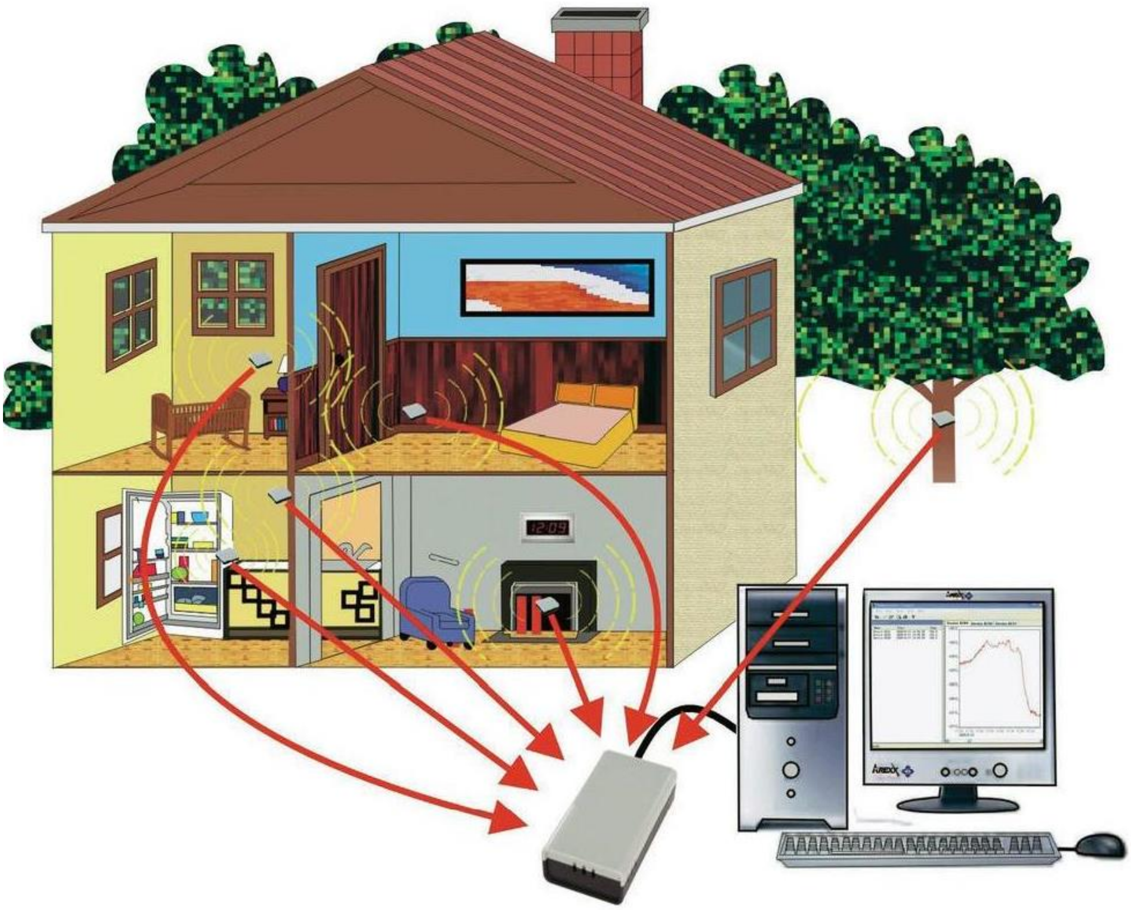

Figure 4.1 The wireless Temperature Logger System

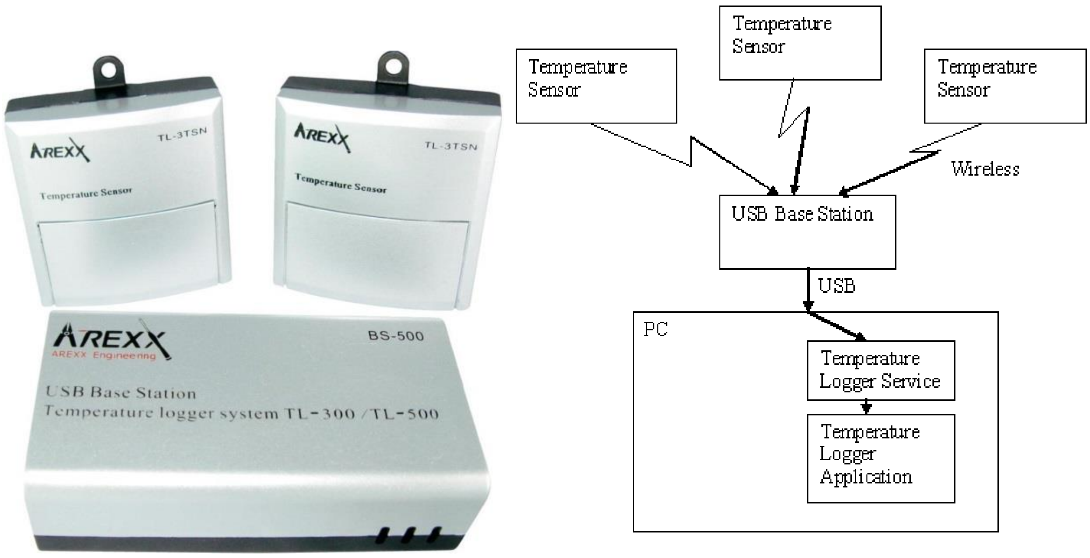

Figure 4.2 The temperature logger application.

4.1.2 External facades surface temperature equipment

For the external facades surface measurements infrared IR temperature gun thermometer where used to record the four facades temperature Figure 4.3.

Figure 4.3 Infrared IR Temperature Gun Digital Thermometer

4.1.3 Electricity consumption equipment

The Owl is a wireless electricity meter that measures the amount of electricity being used in each home 24 hours a day and records it every second. It is simple to install and use, just by clipping the CT provide around the live wire in the meter box and pair the transmitter with the receiver, each electricity meter needs a separate recording device Figure 4.4.

Figure 4.4 The Owl is a wireless electricity meter that measures electricity consumption.

4.1.4 Humidity

There is an electrode in the sensor on a humidity meter, which measures the electrical resistance or capacitance and then sends the signal through the circuitry where it is altered in to a humidity reading Figure 4.5.

Figure 4.5 Humidity reading

4.2 Analysis of the case study

The case study residential building has a rectangular plan and was built in 1999. The building is two storeys high with a total height of 8 m. The ceiling height is 3.5m. The ground floor is 1m above street level and the roof has a sill of one metre.

All the building construction is concrete, where all the internal and external walls are concrete blocks with dimensions of 20cm thick, 20cm height, and 40cm wide, covered from outside with 1-2cm mortar. The roof if was built of reinforced concrete with 45cm thickness in the middle of the building and 25cm at the edge of the roof. Figure 4.6 shows the four facades of the building.

Figure 4.6 The building: four facades.

The floor area is approximately 700m^2 for the first floor; this includes two flats, each of which has two bedrooms, two living rooms, two bathrooms, and a kitchen. The second floor is also divided into two flats, each of these having three bedrooms, two living rooms, a kitchen and three bathrooms. It is occupied as a multifamily residence and the ground and first floors plans are as shown in Figure 4.7 and Figure 4.8 while Figure 4.9 shows the buildings orientation. Flat one is located on the ground floor on the east side, with 8 air conditioners; flat two is located on the ground floor, on the west side, with 6 air conditioners; flat three is located on the first floor, on the east side, with 7 air conditioners, and flat four is located on the first floor, on the west side, with no air conditioning at all.

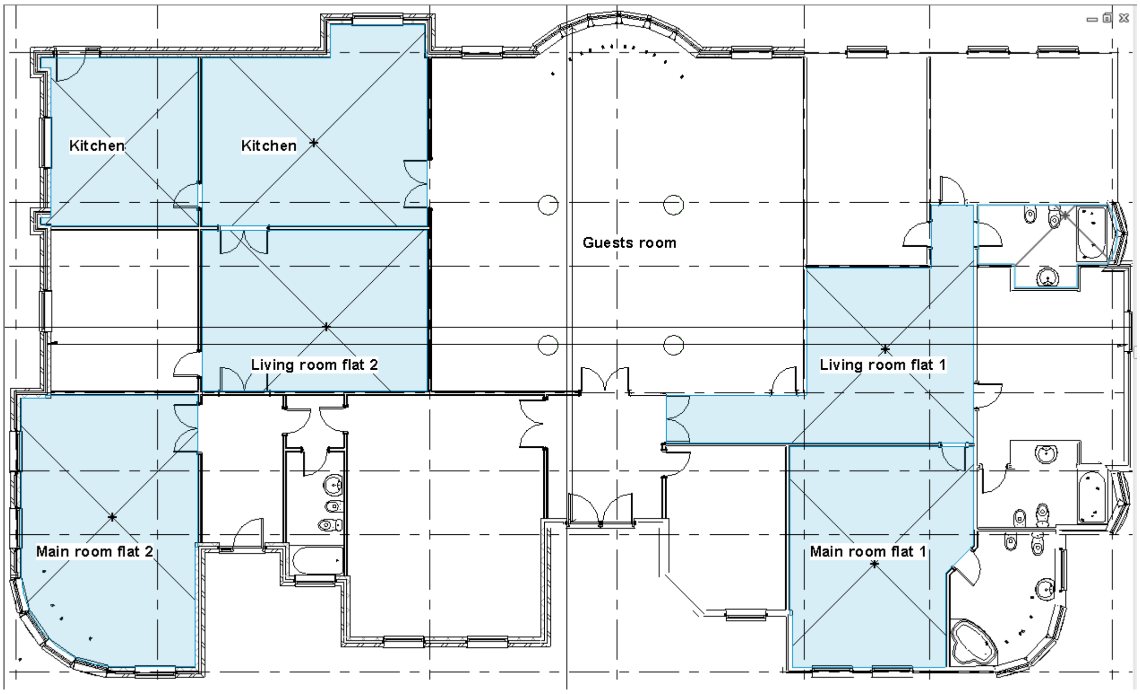

Figure 4.7 Ground floor plan.

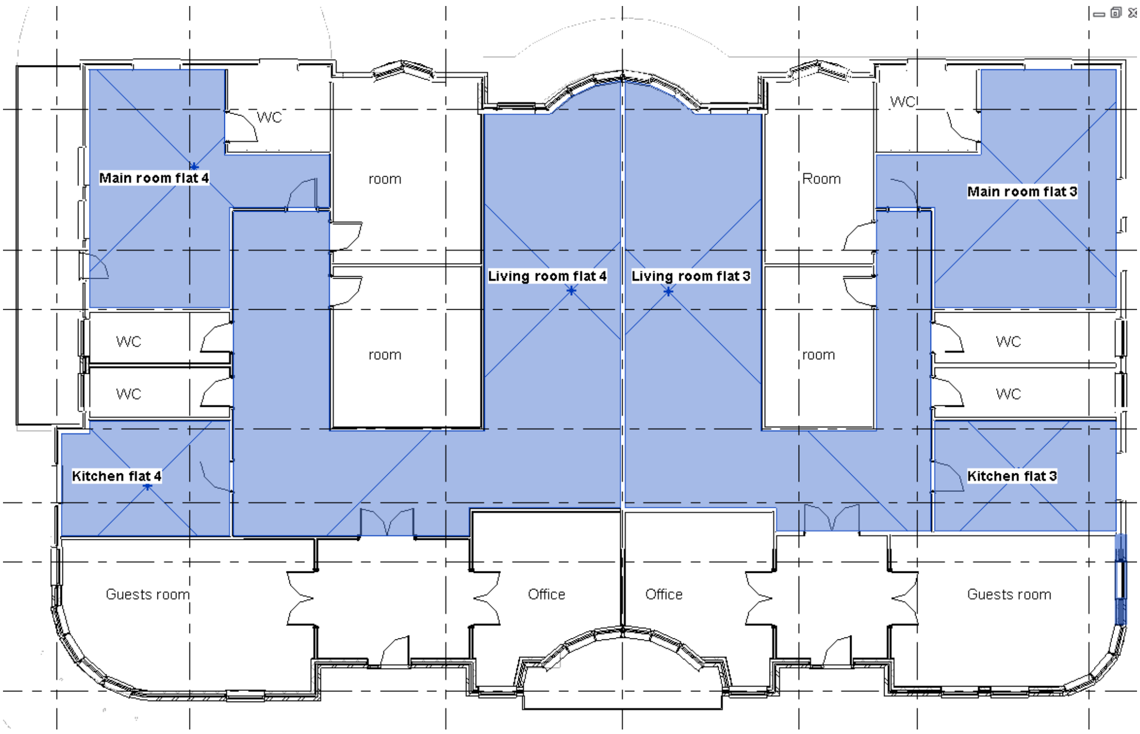

Figure 4.8 First floor plan.

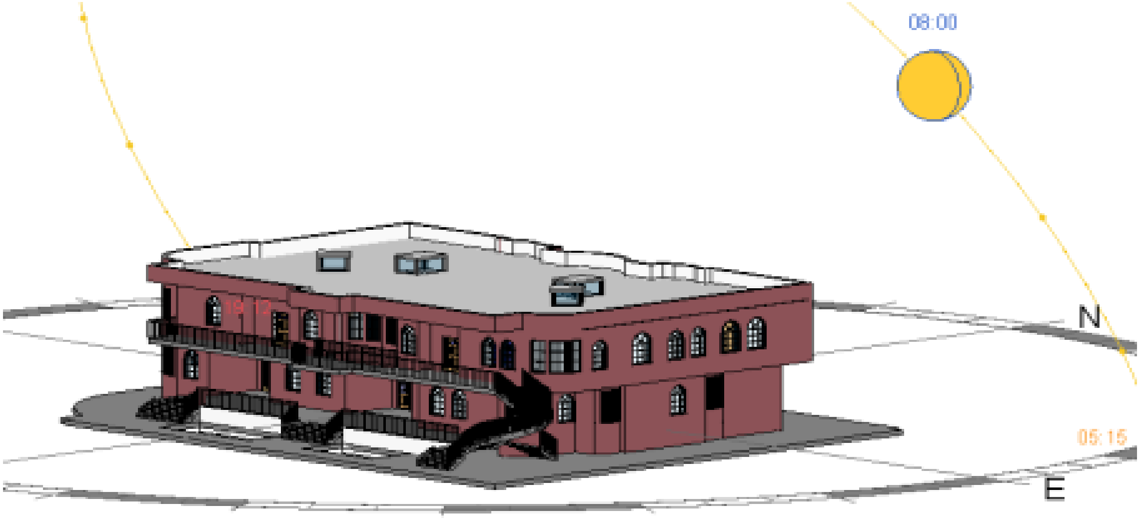

Figure 4.9 Building orientation.

4.2.1 Internal data collected

Figure 4.10 shows the outside air temperature for the whole 45 days continuously, which clearly shows that there are two peak days; in between these days there is a sharp drop in temperature, otherwise the average temperature range is between 27°C-33°C. Three days where chosen and studied in detail, the first being the peak day (21/07/2013), the second day having a low temperature (09/07/2013), and finally a mid-temperature day (08/08/2013).

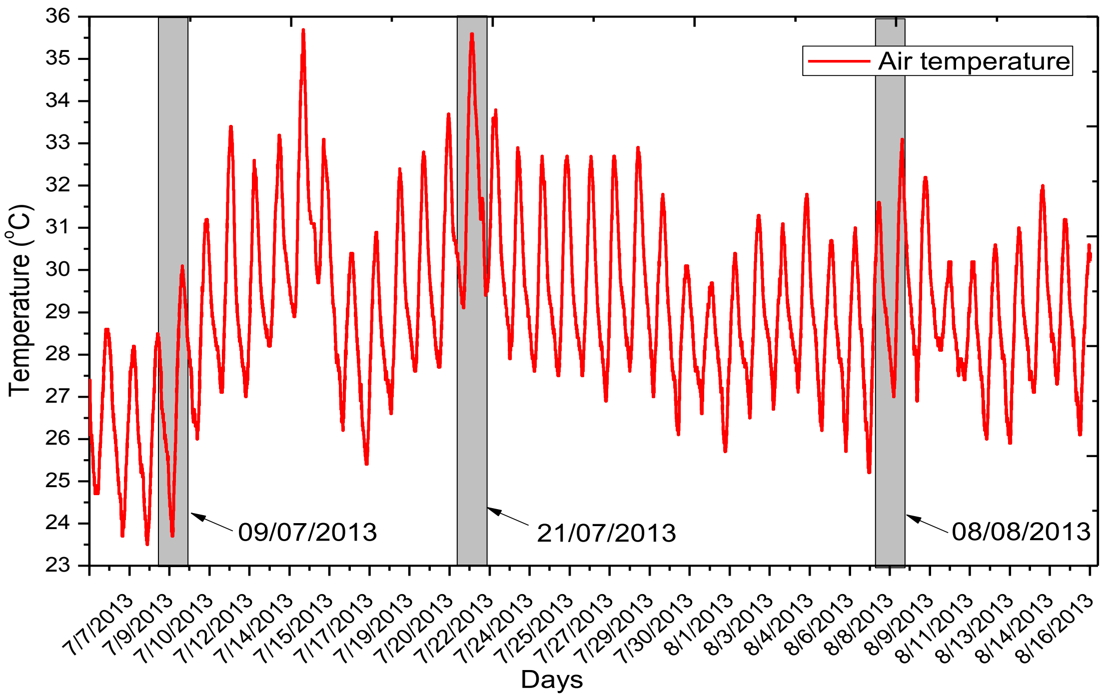

Figure 4.10 Outside air temperature for the whole 45 days studied.

The outside air temperatures for the three days that have been chosen are shown in Figure 4.11.

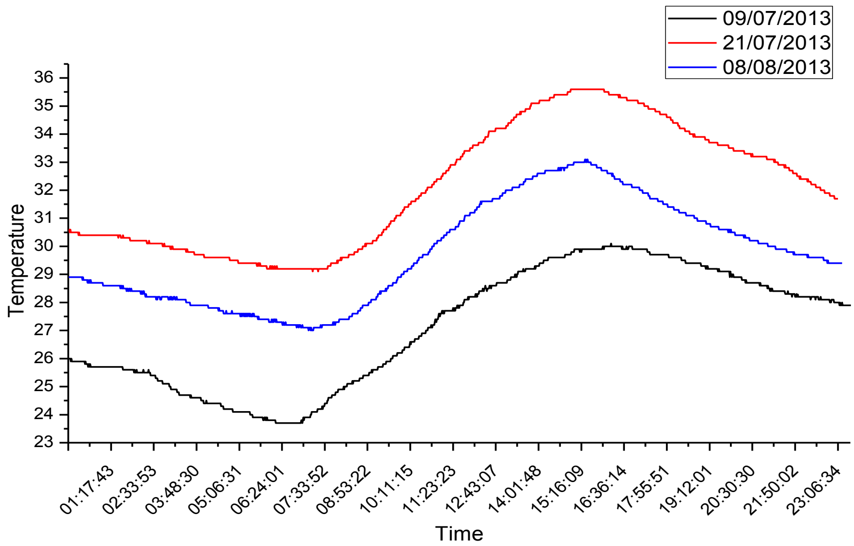

Figure 4.11 Outdoor air temperatures for three days.

From the amount of data collected from the field work, three areas in each flat were studied in detail; the main bed room, the living room, and the kitchen. Furthermore, the basement temperatures and electricity consumption for the whole period of time were also studied (El Bakkush & Harris, Thermal Performance Measurements of a Residential Building Located in Hot Arid Area (Tripoli-Libya), 2015).

4.2.1.1 Main bed rooms

Figure 4.12 Main room flat 1 temperature for the whole study.

Figure 4.12 shows the temperatures in the main room of flat 1, which is located on the ground floor east side, it can be seen that the average temperature is around 28^{o}C, with a temperature generally below the outside temperature, and we also note many of the drops in room temperatures are due to the use of the air conditioner.

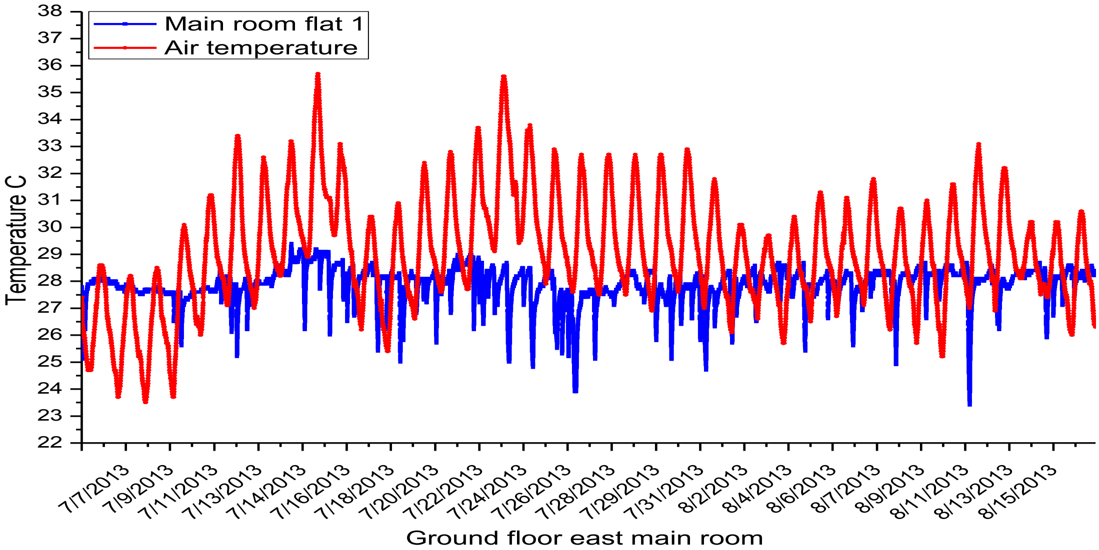

Figure 4.12 Main room flat 1 temperature for the whole study.

The other main bed room on the same floor but on the west side is at a higher temperature than that on the east side Figure 4.13 with an average of around 30^{o}C. It is clear that the room temperature is often higher than the outside temperature, especially in August. Moreover, it is noted that no drops in room temperature occur except on the 26th of July, when it drops by 4^{o}C, due to the air-conditioning which left on.

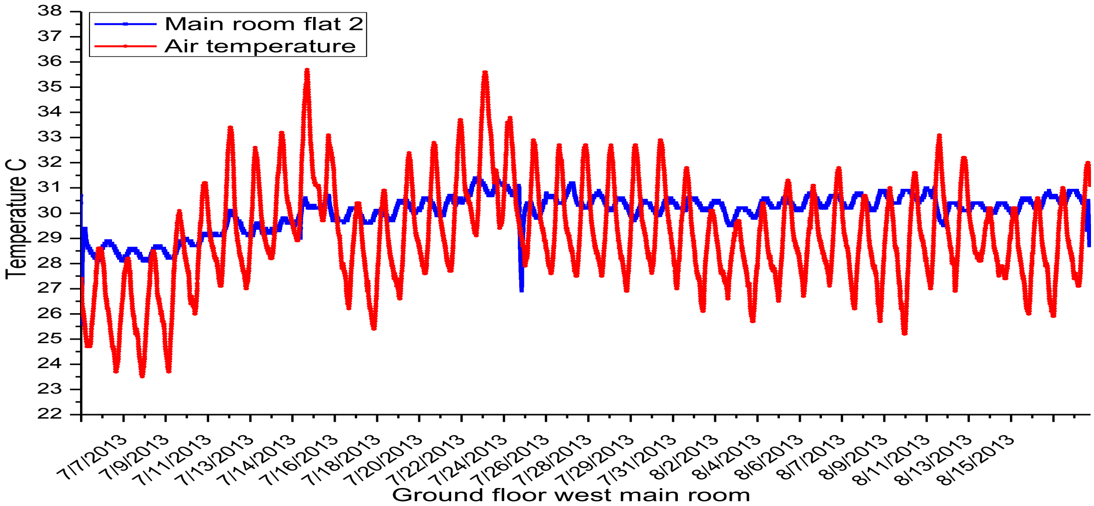

Figure 4.13 Main room flat 2 temperature for the whole study.

The situation is different on the first floor, where the room ceiling absorbs the heat through the roof, which is heated by the sun all day. The main bed room in flat 3 is located on the east side, where the sun heats the wall from sunrise until 12 noon; after that heat is absorbed from the roof. Figure 4.14 shows its relation with the outside temperature, and it is clear that from the 27th of July to the 3rd of August the temperature is higher than at other times. This was due to the fact that the flat was unoccupied at this time and the air conditioners were off, which demonstrates the impact of air conditioning. It plays fundamental part in this case, as when the flat is occupied temperature drops 7^{o}C because of the owner turning on the air-conditioners.

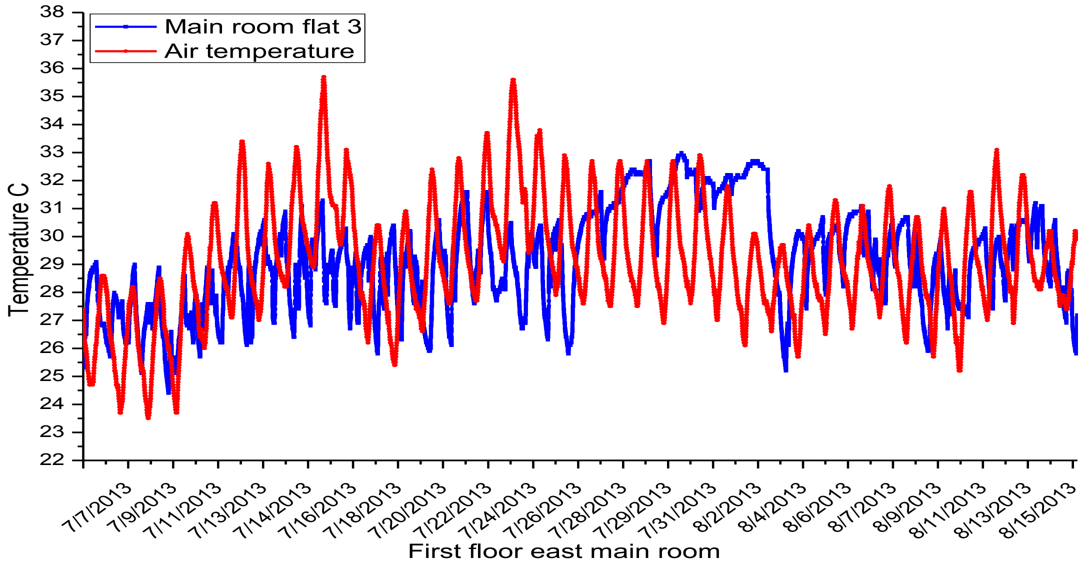

Figure 4.14 Main room flat 3 temperature for the whole study.

The main bed room in flat 4 is very interesting as this flat has no air conditioning, and as it is located on the west side it absorbs the heat from the roof all day and after 14:00 from the west wall also. Because of the lack of air conditioning, the room temperature is always above the outside temperature and follows its rise and fall, as shown clearly in Figure 4.15.

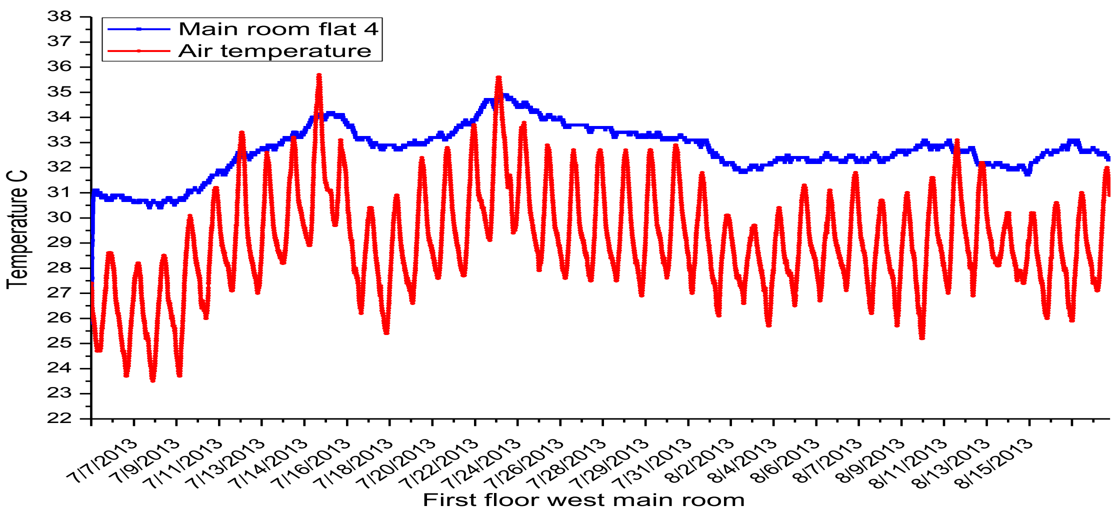

Figure 4.15 Main room flat 4 temperature for the whole study.

To examine and scrutinise the rooms in more detail, all the main rooms' temperatures for the three days that were chosen were compared with the outside temperature. Figure

4.16 shows the outdoor temperature and that of the main bed rooms on the 9th of July. Note that rooms located on the ground floor, i.e. in flats 1 and 2, have a fairly steady temperature, while the room located on the west side in flat 2 is almost one degree higher than the room on the east side in flat 1. Furthermore, in flat three the room temperature drops with the drop of external temperature early in the morning, and rises with the rise in external temperature; at 27°C the air conditioning is switched on and starts cooling, and as soon as the A/C is switched off the temperature rises again. As for the room in flat 4, (with no air conditioning), the temperature is stable at around 31°C and is higher than the outside temperature. This room is located on the second floor and on the west side.

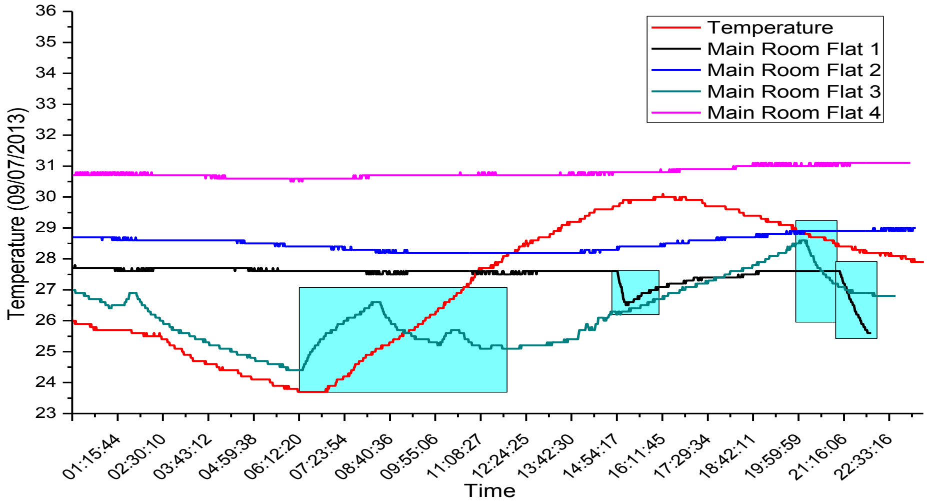

Figure 4.16 Main room temperatures on 09/07/2013.

Focusing on the 21st of July and 8th of August, the temperature in the room in flat 4 is, as usual, higher than that in the other rooms, with average temperature of 33°C to 34°C, and flat 2 is stable at around 31°C. Moreover, in flats 1 and 3 the rise and fall in temperature as a result of switching the air conditioning off and on can also be seen in Figure 4.17a and 4.17b.

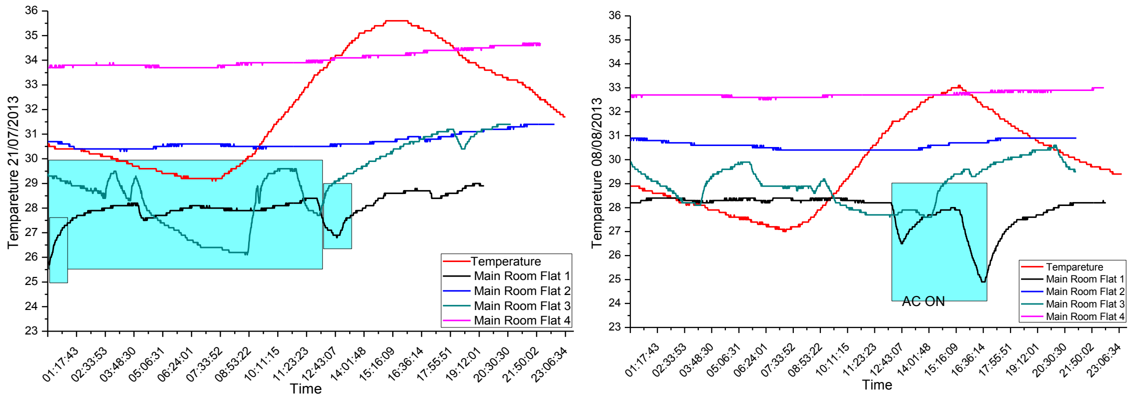

Figure 4.17 Main room temperatures on a) 21st of July and b) 8th of August

4.2.1.2 Living rooms

The second area studied was the living room. Figure 4.18 shows the relationship between outside temperature and that in the living room in flat one, located on the ground floor east side. The average temperature is 28°C but it is clear that there are a lot of drops of around 3°C because of turning living room air-conditioners on, even though the outside temperature has risen; this will be clearer afterwards when we examine conditions in the living rooms over the three days.

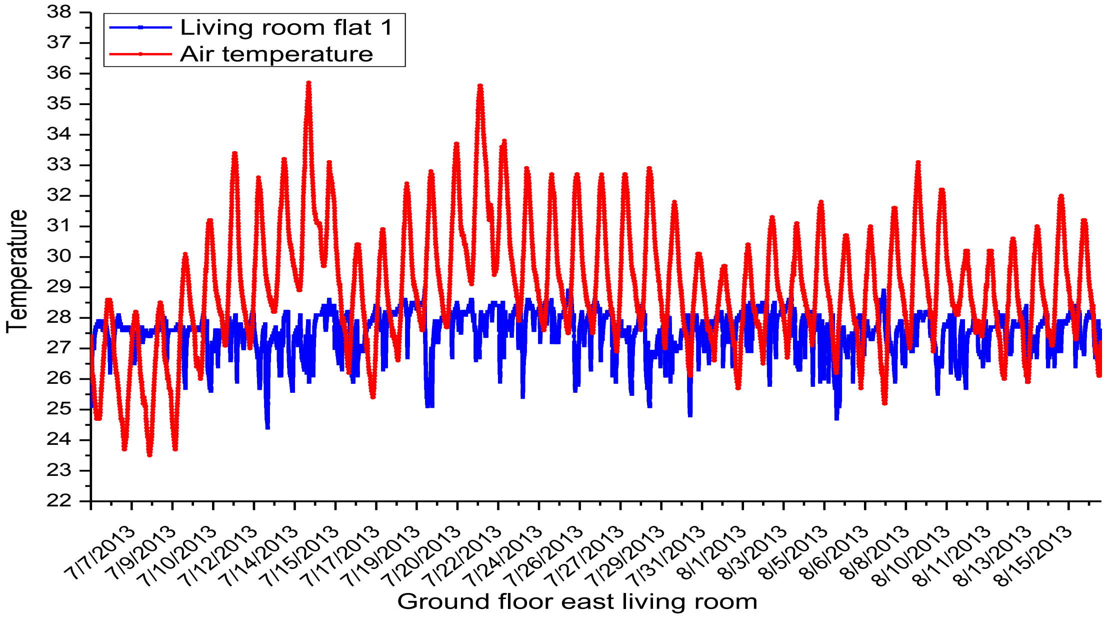

Figure 4.18 Living room flat 1 temperature for the whole study period.

In the living room in flat two the temperature is unstable, sometimes following the outside temperature, but at other times forced to decrease because of turning on the air conditioning and showing significant decreases on 12th and 18th of July or the 10th of August as shown in Figure 4.19.

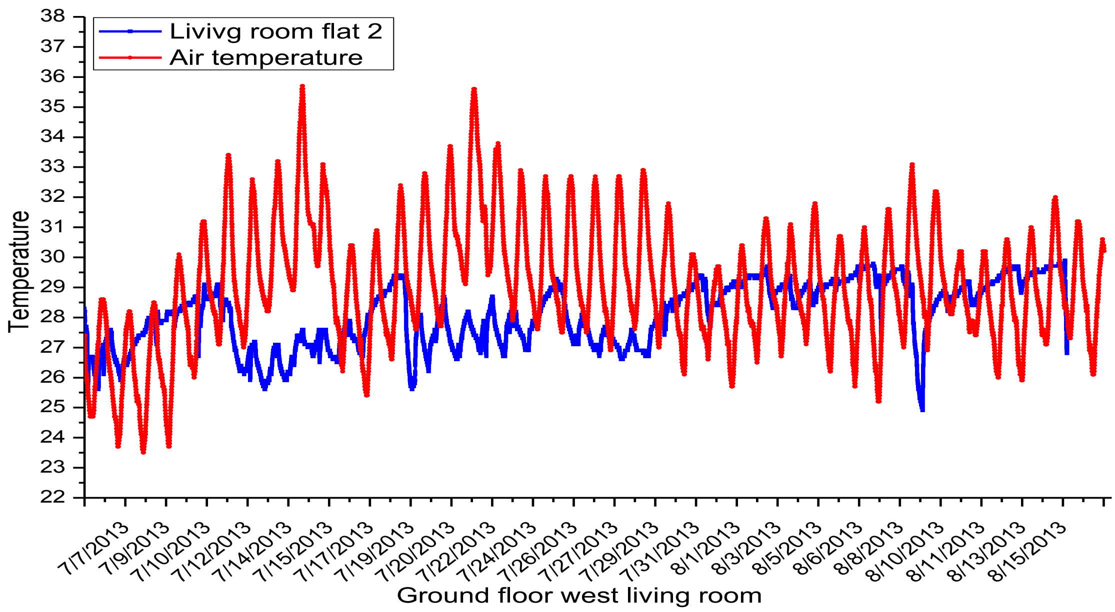

Figure 4.19 Living room flat 2 temperature for the whole study period.

Figure 4.20 shows the living room temperatures in flat 3, where the temperature is in the middle of the outside temperature range at the beginning of July; the other fundamental issue is that in the same period of time from the 27th of July to the 3rd of August the temperature is higher than the outside temperature because the flat was unoccupied and the air conditioning was off.

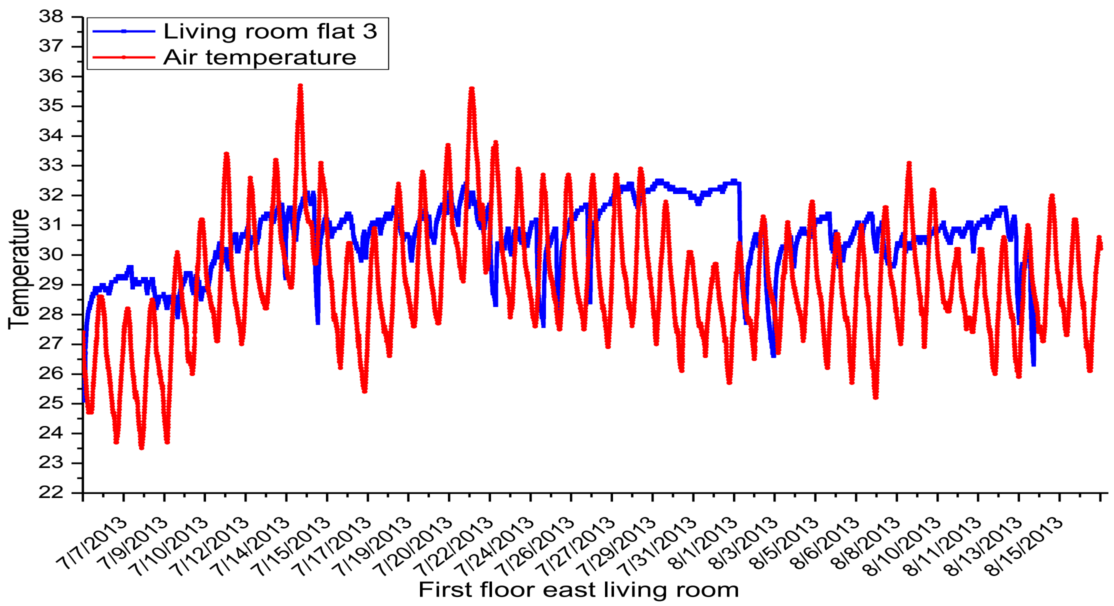

Figure 4.20 Living room flat 3 temperature for the whole study.

With no air conditioners on, living room temperatures follow the outside temperature but 4°C higher, and the average temperature of 33°C is very hot Figure 4.21.

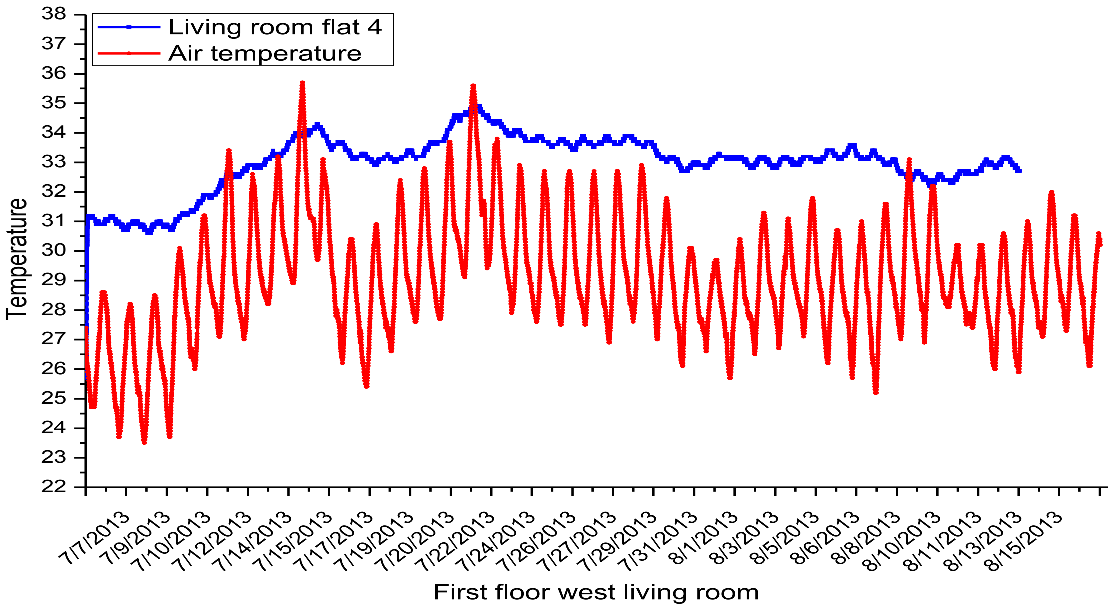

Figure 4.21 Living room flat 4 temperature for the whole study.

Figure 4.22 shows that the living room temperatures on the 9th of July for flats 1, 2 and 3 are on average between 27°C and 29°C, except in the living room in flat 1 where the peak day temperature in the late afternoon temperature dropped two degrees, while the living room in flat 4 is above the outside temperature at around 31°C.

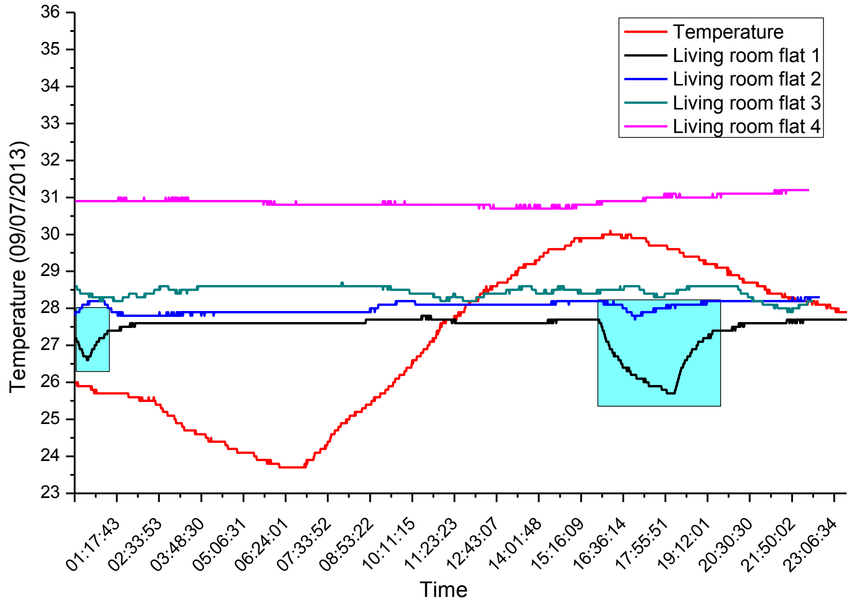

Figure 4.22 Living room temperature for the 9th of July.

Figure 4.23 shows the living room temperatures for the 21st of June and the 8th of August, and it is clearly shown that the living room temperature in flats 1 and 2 is unstable, whether the room is occupied or not; on the other hand the living room temperature in flat 3 is stable, as well as that in the living room in flat 4, although it is at the highest temperature.

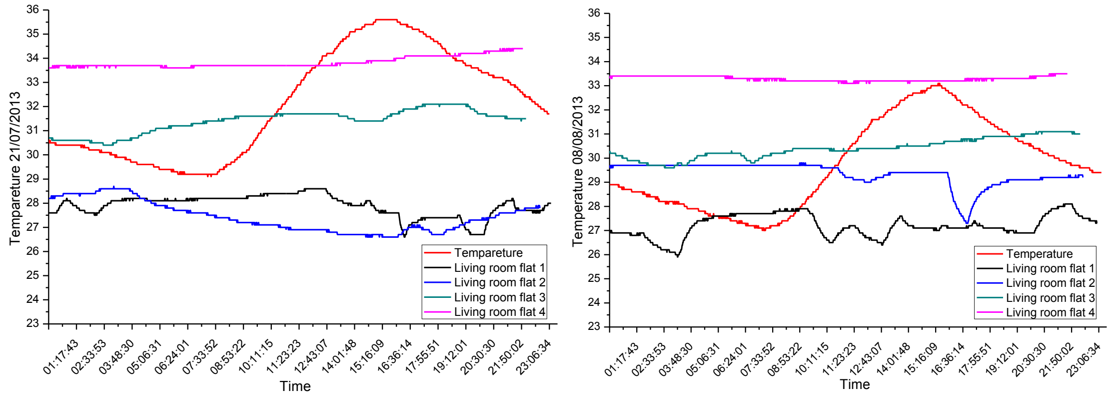

Figure 4.23 Living room temperatures for 21st of July and 8th of August.

4.2.1.3 Kitchen

The other important room is the kitchen, which is not less important than any other room because of the culture and traditions, in which women spend almost of their time in the kitchen; therefore, the temperature in this very important room should suitable and comfortable. Unfortunately the sensor in the kitchen in flat two did not work properly; therefore results for this kitchen are excluded. The kitchen temperature is often higher than other rooms, due to a number of factors including heat gains from the cooker, kettle, fridge, and freezer. Figure 4.24 shows kitchen temperatures in flat one which are generally round about the average of the outside temperatures, with an average of 30°C.

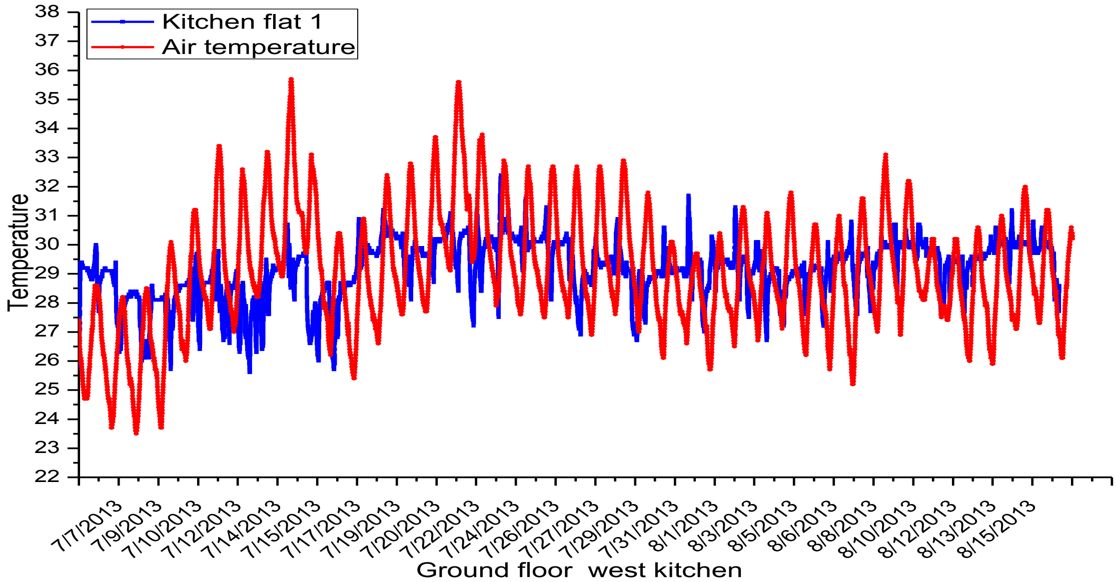

Figure 4.24 Kitchen flat 1 temperature for the whole study.

Flat three kitchen temperature is variable, with many falls and rises as the air conditioning is switched on and off. The A/C is on almost of the time except during the unoccupied period, and it is evident that without air conditioning the temperature would be above the outside temperature, as shown in Figure 4.25.

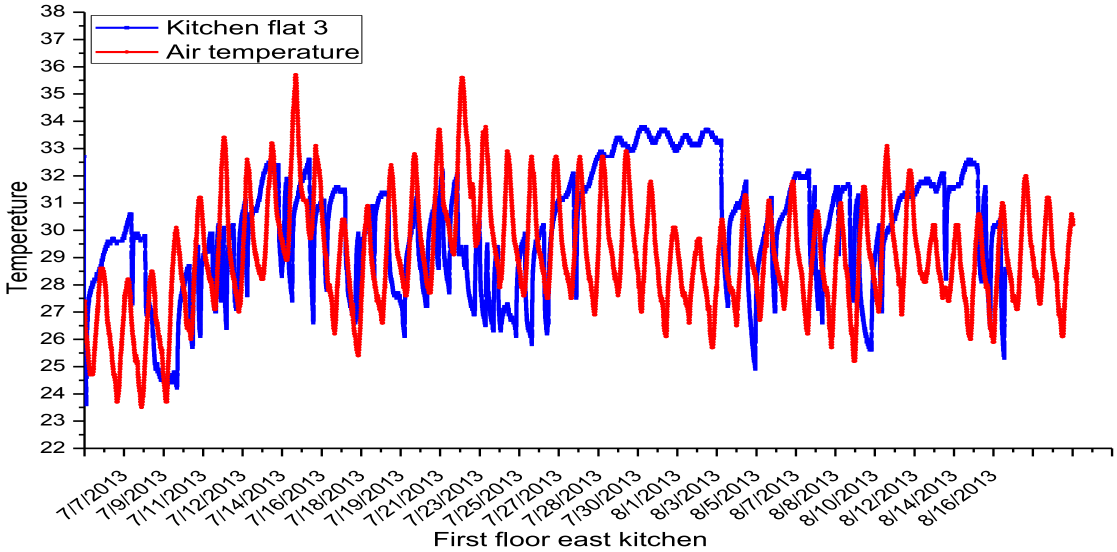

Figure 4.25 Kitchen flat 3 temperature for the whole study.

Figure 4.26 shows the kitchen in flat four and, as usual, the temperature is always above the outside temperature and at around 35°C is unacceptably high.

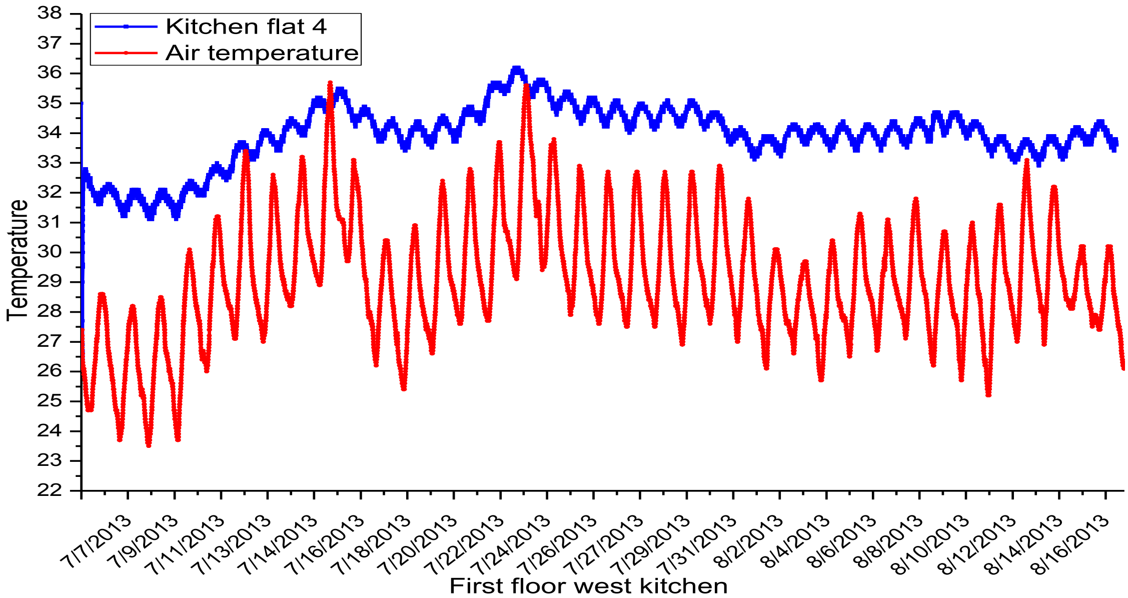

Figure 4.26 Kitchen flat 4 temperature for the whole study.

For more details Figure 4.27 shows the kitchen temperatures on the 9th of July for all flats, and it is clear that the kitchen in flat 1 is stable at slightly above 28°C, until the middle of the day, although with the rise in temperature outside, the kitchen temperature falls due to the air conditioning running; furthermore the temperatures in the kitchen in flat 3 were stable due to the absence of residents on that day. Note that the temperature climbs suddenly in the last hours of the day even though the external temperatures fall, due to the time lag. As for the kitchen in flat 4, as before, the temperature is stable at around 32°C, and is higher than the temperature outside the building: note again that that the temperature is out of phase with the outdoor temperature by about 5 hours, due to the time lag.

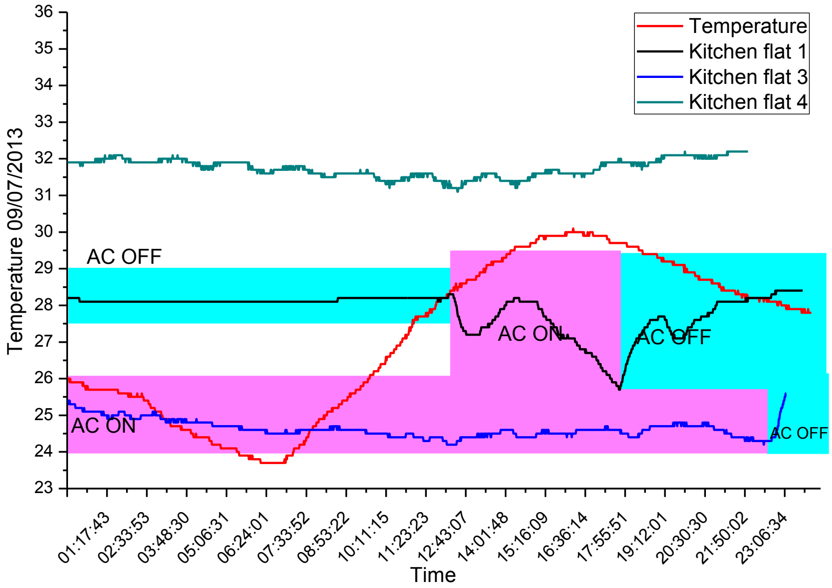

Figure 4.27 Kitchen temperature for the 9th of July.

Figure 4.28 shows how the A/C plays a significant role in changing the temperature inside the kitchen and also shows how the temperature returns back to normal after switching it off. On the 21st of July the air conditioning in the kitchen of flat 3 was on until 4 am, however, after switching the AC off the temperature increased by about 3°C and continued rising gradually until it reached 31°C, when the air conditioning was switched on and the temperature fell to around 28.5°C, while the outside temperature reached a peak of 35.5°C. Moreover when the A/C was switched off again the temperature increased to 32°C, and after running the A/C it fell to 28.5°C. Similar comments apply to the data for the 8th of August.

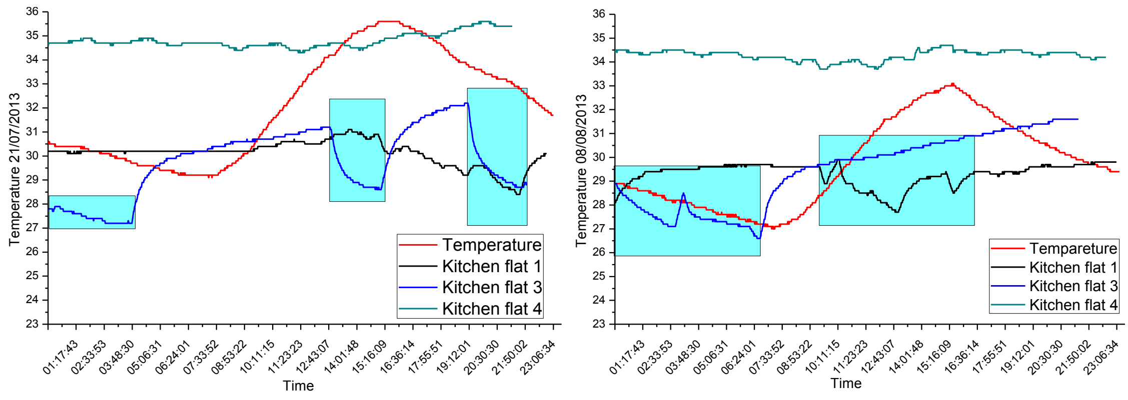

Figure 4.28 Kitchen temperatures on 21st of July and 8th of August.

4.2.1.4 Basement

The other important observation is that the basement temperature is not greatly affected by the outside temperature. Taking a closer look at the three days we find that no matter how the outside temperature rose or fell, the change in basement temperature is limited to around one degree Celsius, as shown in Figure 4.29.

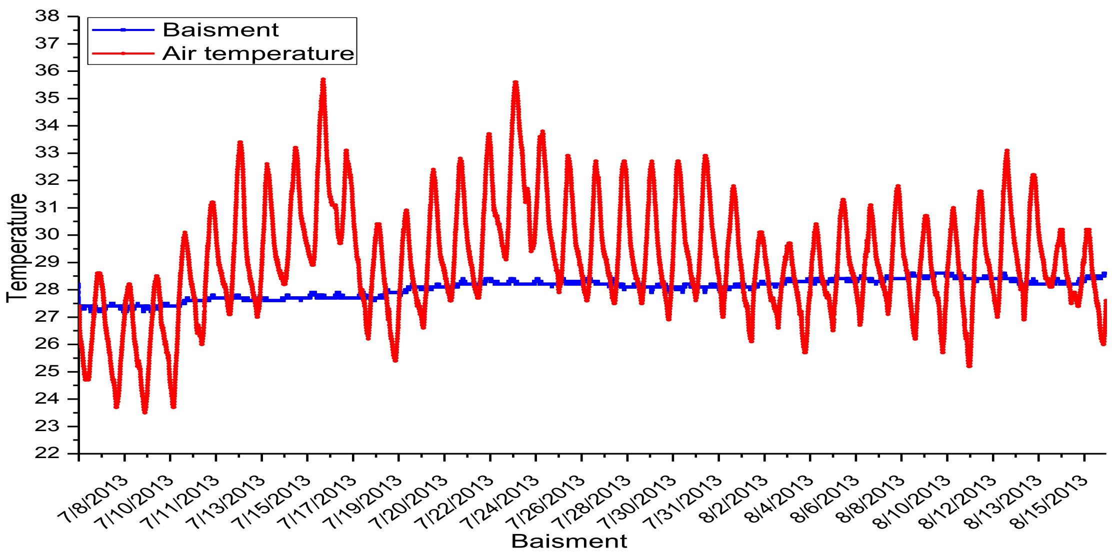

Figure 4.29 Basement temperature for the whole study.

To clarify the relationship further, Figure 4.30 shows the relationship between the outside temperature and the temperature of the basement for the three days.

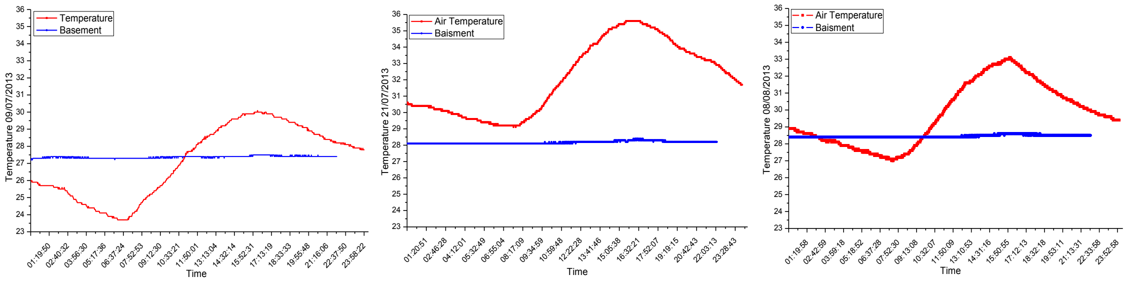

Figure 4.30 Basement temperatures on the 9th & 21st of July and the 8th of August

4.2.2 External data collection

4.2.2.1 Facades

In general, each façade has been divided into four main groups, the first floor walls, second floor walls, first floor glazing and the second floor glazing. These measurements were taken for the four facades and each orientation studied separately. Figure 4.31 shows the data for the north façade for the whole period of the study, and clearly shows that temperatures for the entire northern facade are in harmony, increasing and decreasing by the same amount in relation to the outside temperature. Moreover, the records indicate that the external temperature is generally higher than that of the façade.

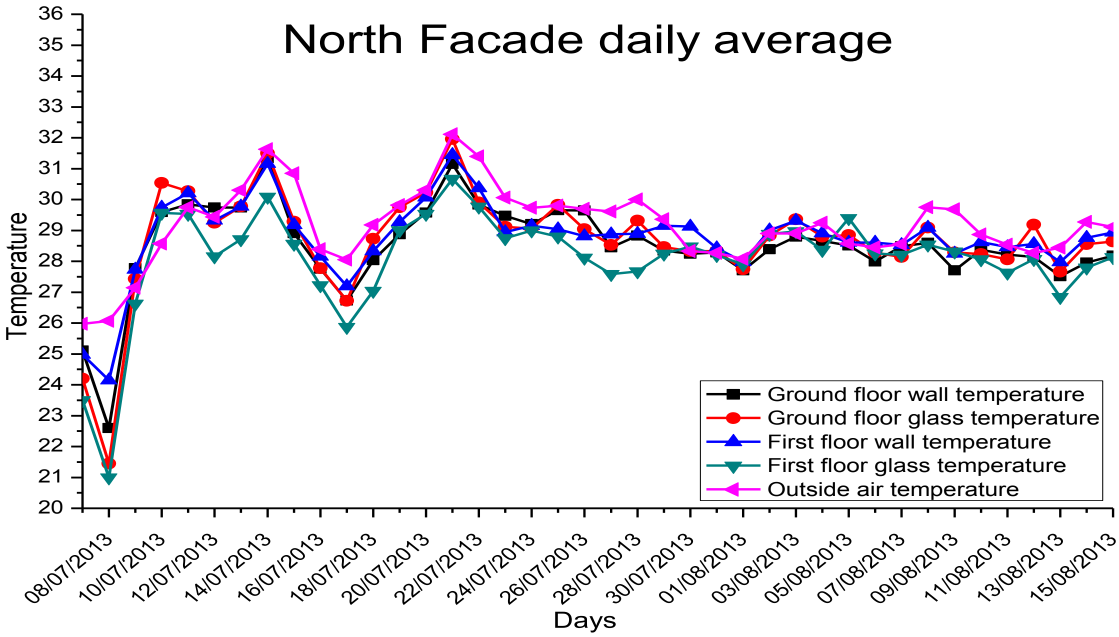

Figure 4.31 The whole study temperature recorded for the north façade.

The trends to not differ much for the southern façade, in terms of temperature and their relationship between the different elements, the only clear difference being that the outside temperature is below that for all other elements, as can be seen in Figure 4.32.

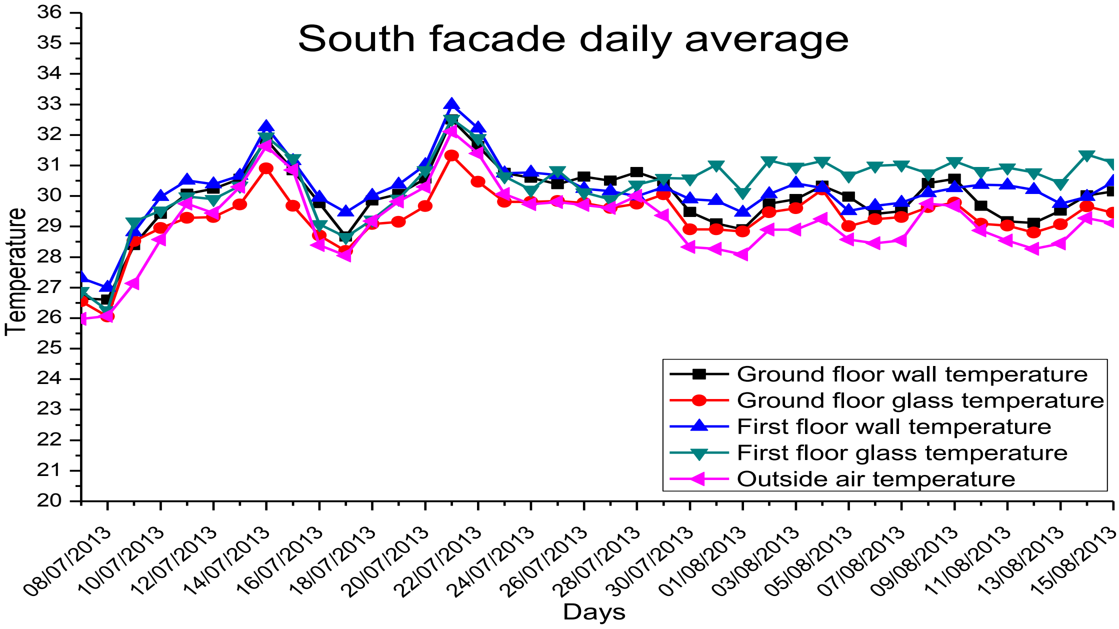

Figure 4.32 The whole study temperature recorded for the south façade.

A more diverse pattern clearly can be seen in the results from the eastern façade, Figure 4.33, showing a small difference of up to 1^{o}C between the ground floor glass and the other elements, where the ground floor glass temperature is less than that of other elements, while the outside temperature is in general, below them all.

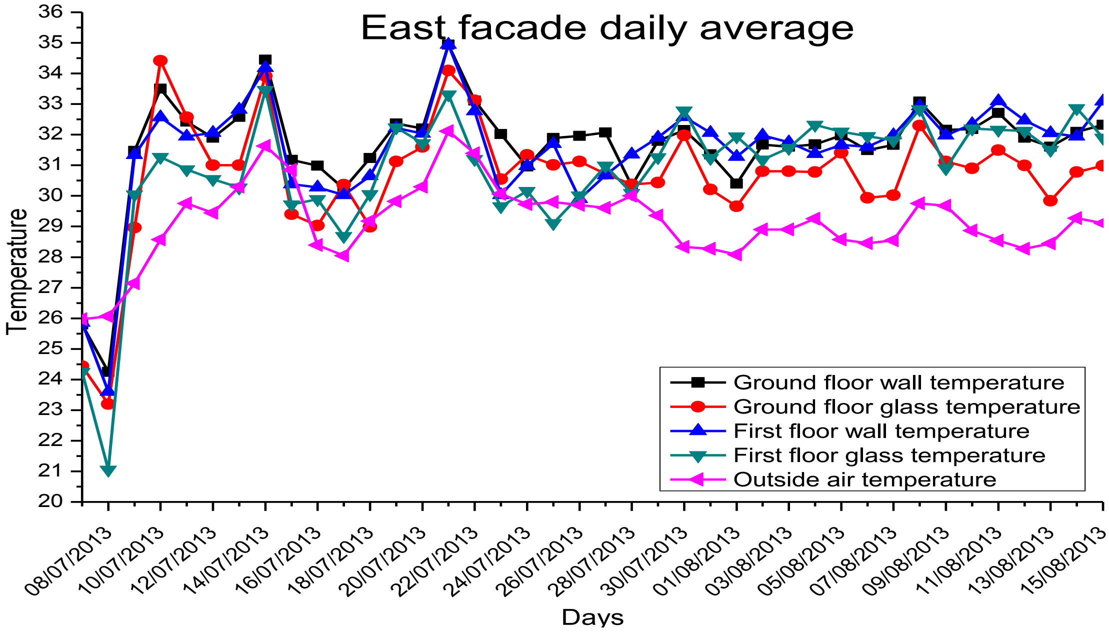

Figure 4.33 The whole study temperature recorded for the east façade.

In the west façade there is a clear difference in first and ground floor glass temperature; the first floor glass is at a lower temperature than the others, which is the opposite situation to the east façade; this is due to solar position, as shown in Figure 4.34.

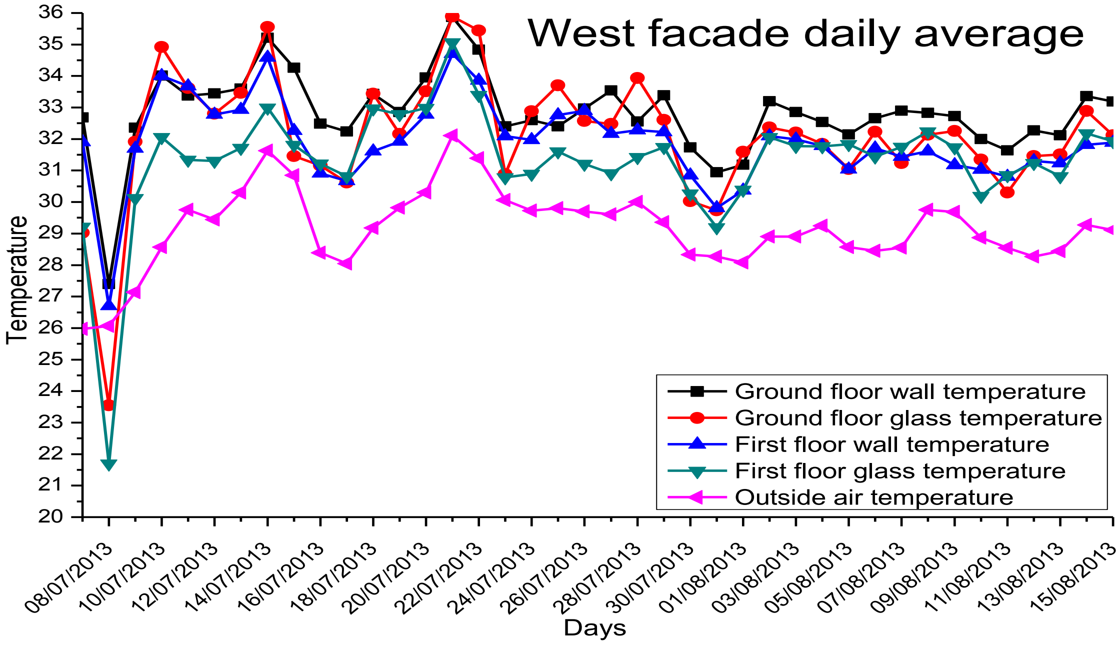

Figure 4.34 The whole study temperature recorded for the west façade.

Focusing on the three days, for the 9th of July all patterns are consistent with the external temperature, except the east and west façades, for both walls and glass, as can be seen in Figure 4.35. From 04:00 the wall temperature starts to increase until mid-day, when the temperature reaches 44°C; this is because the sun at that time is directly facing the façade, and is then heating the western façade until mid-night, while the roof surface starts absorbing the heat from 08:00 until it reaches 62°C at 14:00.

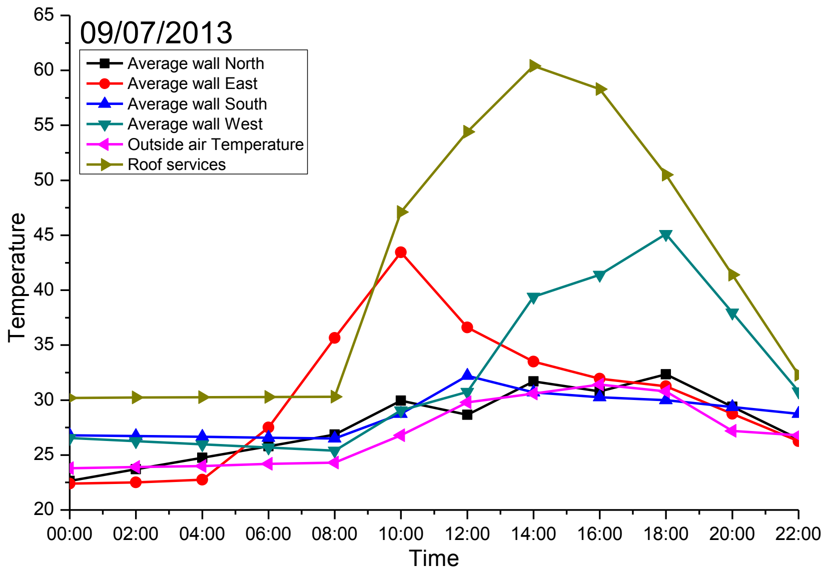

Figure 4.35 The relation between the average wall and roof surface temperatures equally with the outside temperature on the 9th of July.

This relationship applies equally to the glass in both facades and the roof surface as shown in Figure 4.36.

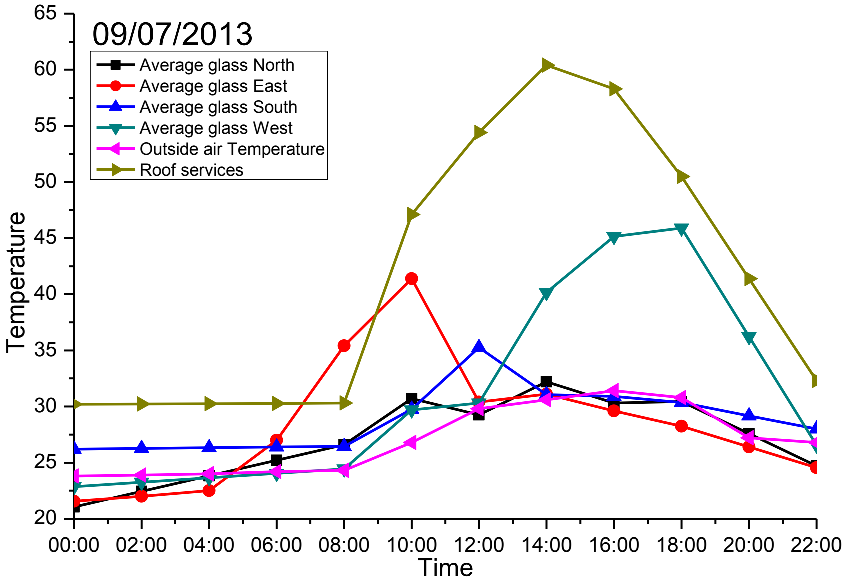

Figure 4.36 The relation between the average glass and roof surface temperatures with the outside temperature on the 9th of July.

In respect to the two other days, the 21st and the 8th of July, as shown in Figure 4.37, the north and south façade are in harmony with the outside temperature following its increase and decrease, while the temperatures of the eastern and western facades are also increasing and decreasing at the same times of the day, as temperature starts to increase from 06:00 early morning and continues increasing until it reaches the peak at 10:00am, where the wall temperature reaches up to 48^{o}C on the 21st of July and up to 52^{o}C on the 8th of July. The wall temperature starts to drop gradually until it meets the pattern at 16:00; on the other hand, the temperature of the glass increases to reach the peak at 18:00, while the roof surfaces reach the peak between 14:00 and 16:00, with temperature above 60^{o}C.

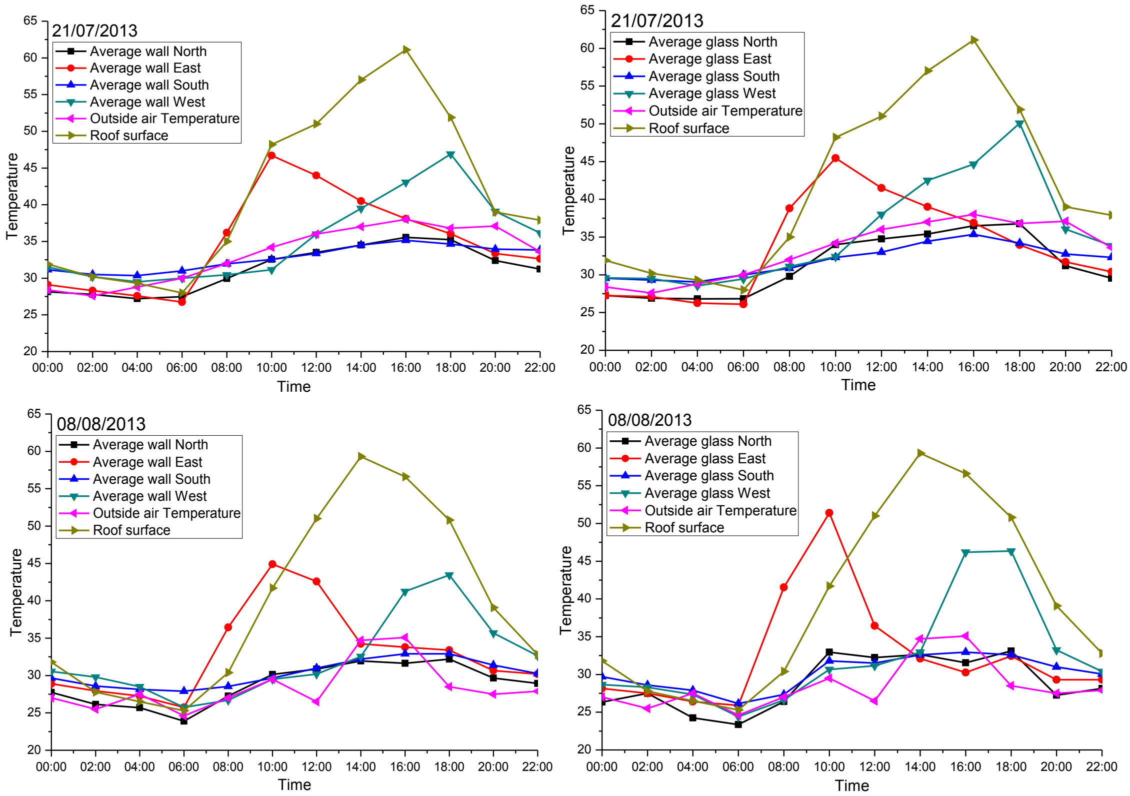

Figure 4.37 The relation between the average wall and glass temperatures and roof surface with the outside temperature on the 21st of July and the 8th of August.

Figure 4.38 shows the average temperature of all walls and glass for each elevation and a comparison with the roof and outside air temperature; as can be seen on the 9th of July, the north and south façade are stable and harmonised with the outside temperature, while roof surface reaches a peak at 14:00, with more than 30°C difference.

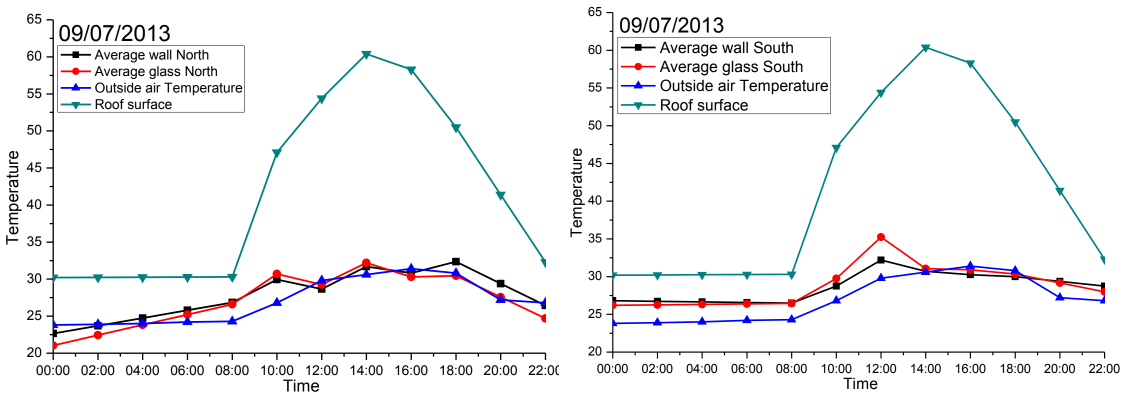

Figure 4.38 The relation between the average wall and glass temperatures and roof surfaces with the outside temperature on the 9th of July for the north and south façades.

The east façade temperature rises when the sun rays start to hit the façade in the early morning. As shown in Figure 4.39, the temperature jumps to 44°C, with a difference of 18°C between the facade temperature and air temperature by 10:00, and starts to drop down when the sun is perpendicular to the building at 12:00 noon. On the other hand, the west façade temperature starts to rise at 12:00 noon, to reach a peak at 18:00 at 46^{o}C, while at 22:00 it falls to close to the other wall temperatures. The roof surface temperature rises along with that of the east façade and continues rising until 14:00, to reach 62^{o}C, and then falls along with that of the west façade.

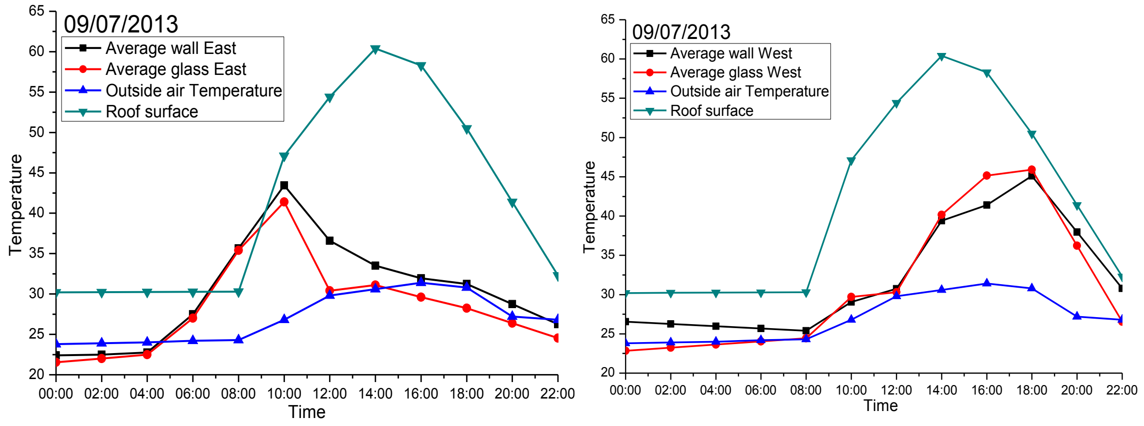

Figure 4.39 The relation between the average wall and glass temperatures and roof surface temperatures with the outside temperature on the 9th of July for the east and west façade.

Figure 4.40 shows the north and south façade temperature on the 21st of July and it is evident that the wall and glass temperature are in harmony and show a smooth relationship with the outside temperature, while the roof surface absorbs heat gains the whole day.

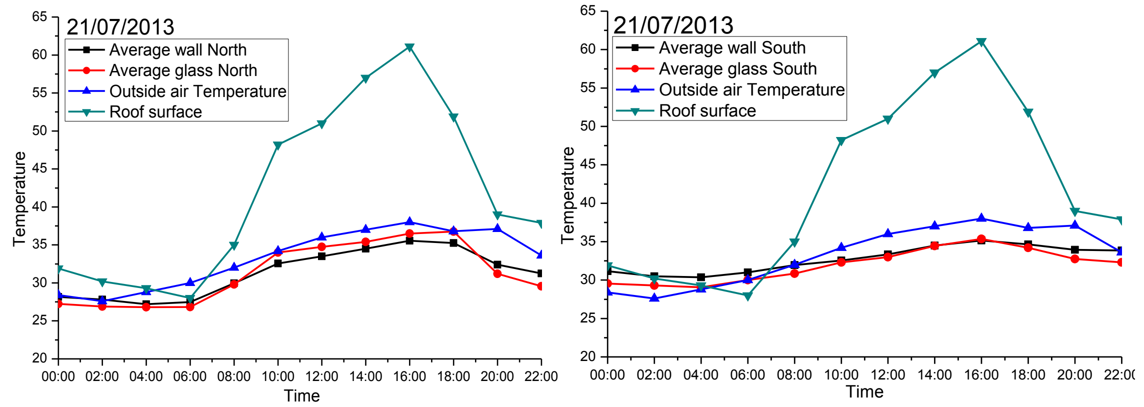

Figure 4.40 The relation between the average wall and glass temperatures and roof surface temperatures with the outside temperature on the 21st of July for the north and south façade.

On the 21st of July it can be seen from Figure 4.41 that the east façade temperature jumps by almost 22^{o}C to reach 48^{o}C in the four hours from 06:00 to 10:00; from then the temperature began to fall gradually. Furthermore, on the west façade the temperature from midnight until 10:00 is fairly stable and from then on the temperature starts to increase gradually until it reaches a peak at 18:00, with 50^{o}C, and then falls within two hours to a similar level to that of the other facades; as usual the roof surface temperature rises with that of the east façade and drops with that of the west façade, reaching above 60^{o}C.

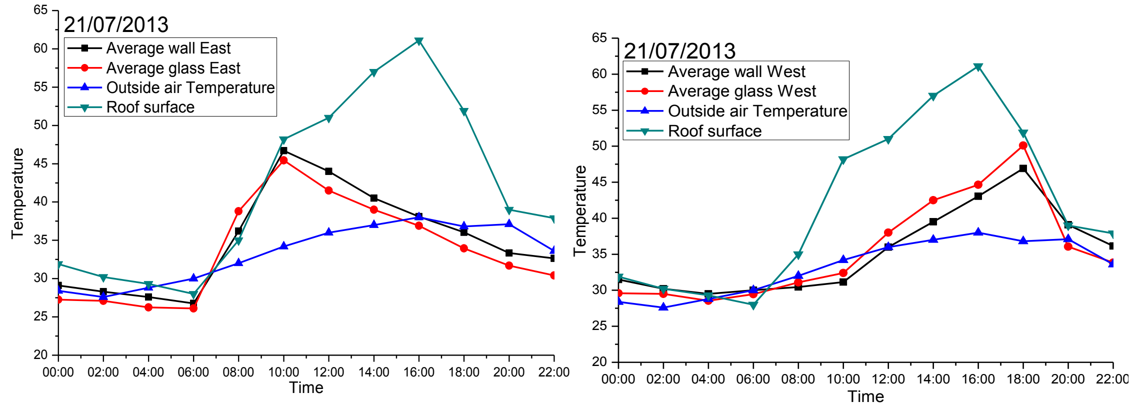

Figure 4.41 The relation between the average wall and glass temperatures and roof surface temperatures with the outside temperature on the 21st of July for the east and west façade.

On the 8th of July, the situation is slightly different, due to the presence of some clouds, where the rise in temperature on the east façade is much lower; however, the temperatures of the wall and glass are similar to those found previously on the north and south facades, as shown in Figure 4.42.

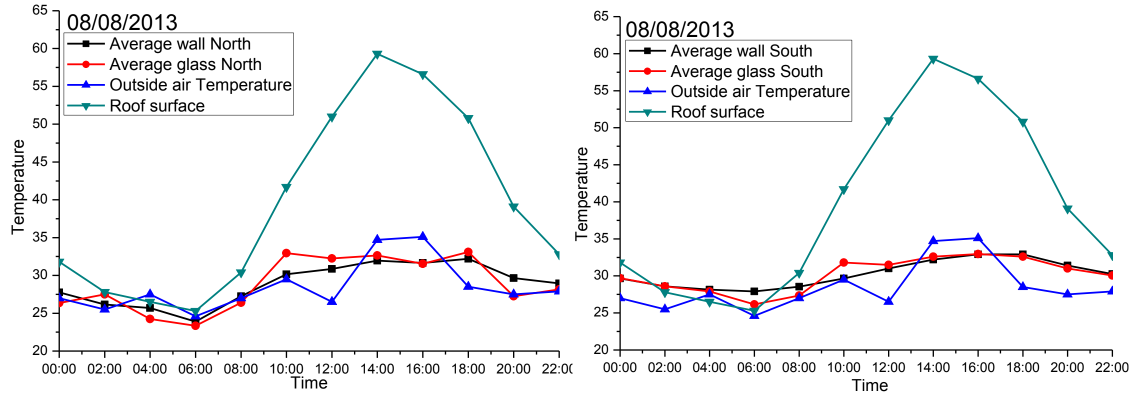

Figure 4.42 The relation between the average wall and glass temperatures and roof surface temperatures with the outside temperature on the 8th of July for the north and south façades.

It is completely different for the east and west façades: although the air temperature is unstable, the wall and glass temperature on the east facade, as usual, starts to increase at 06:00 until it reaches a peak of 52^{o}C, at 10:00. After that it starts to decrease gradually until 14:00, when the west façade temperature starts to increase, to reach 46°C at 18:00; however, the roof surface is slightly different in that the east façade temperature rises before that of the roof, which is unusual, as shown in Figure 4.43.

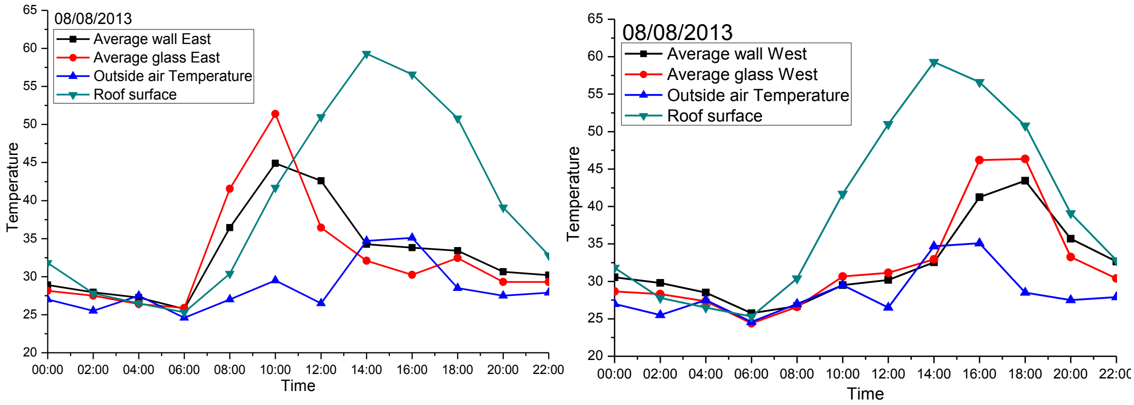

Figure 4.43 The relation between the average wall and glass temperatures and roof surface temperatures with the outside temperature on the 8th of July for the east and west façade.

To study each façade in more detail, a comparison is shown of the three days the 9th, 21st of July and the 8th of August, for each façade, shown in Figure 4.44. For the north façade, temperature is stable for the three days: it starts to rise at 08:00 as the outside temperature rises, as expected, and although different days undergo different temperatures the roof surface temperature follows a similar pattern on each day and reaches similar temperatures.

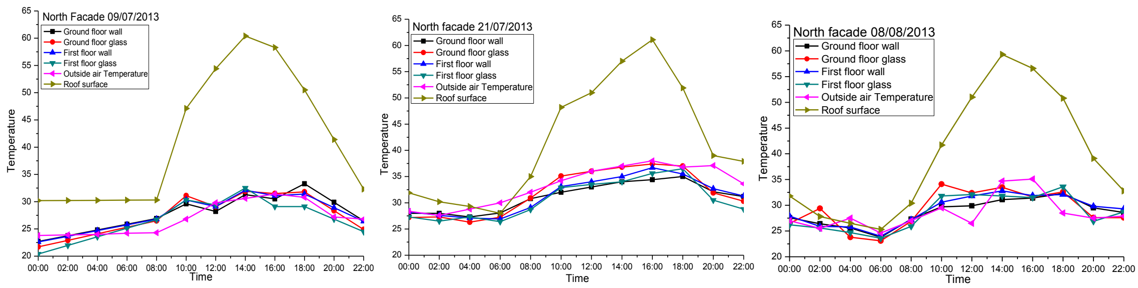

Figure 4.44 Comparison between the three days for the north façade.

Figure 4.45 shows the south façade and there is little difference from the north façade.

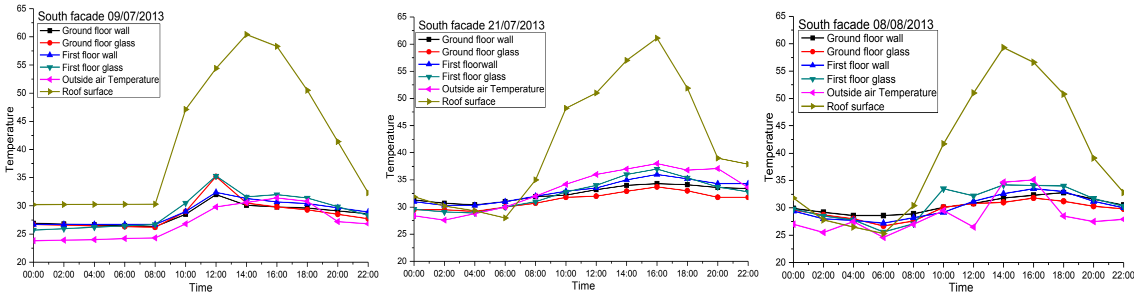

Figure 4.45 Comparison between the three days for the south façade.

The graph for the east façade, Figure 4.46, shows that at 06:00, walls, glass and roof start to absorb the heat, because of the sun's rays hitting the façade from sunrise until 10:00. After 10:00 the wall and glass start to cool down, while the roof continues to absorb the heat until 14:00, when the sun moves from the vertical position above the building.

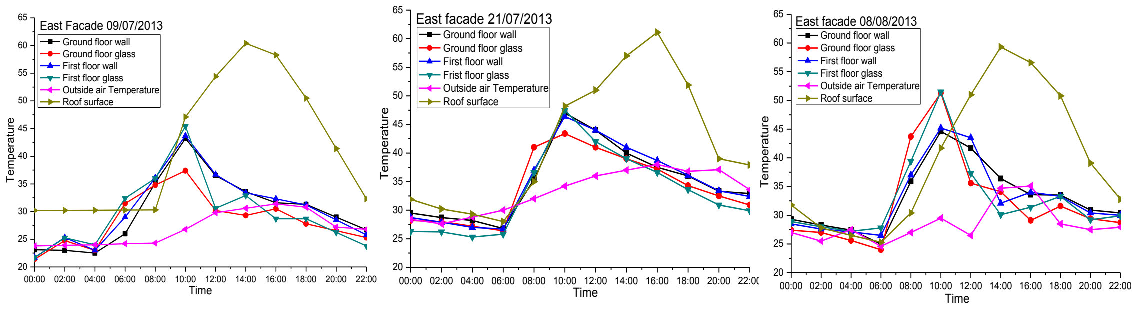

Figure 4.46 Comparison between the three days for the east façade.

The behaviour of the west façade in Figure 4.47 is completely opposite to that of the eastern façade: after midday, when the sun starts to hit the western façade, the façade starts to heat up until sunset at 18:00, at which time the wall and glass temperature meet with the roof surface temperature and cool down together, the heat being transferred to inside the building, as it was noticed that first floor temperature rises at night while on the ground floor spaces on the east side start to heat up until midday, while spaces on the west side start to heat after 16:00, because of the time lag for the heat transfer from outside to inside through the bricks and glass.

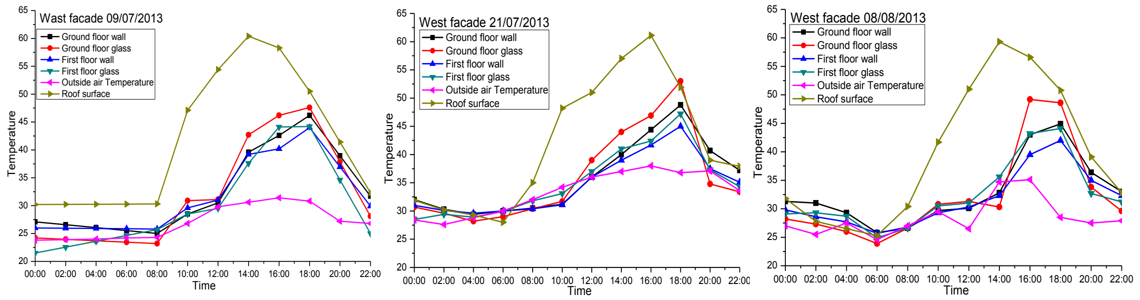

Figure 4.47 Comparison between the three days for the west façade.

Placing the roof temperature under inspection for the three days, Figure 4.48 shows the temperatures for those three days.

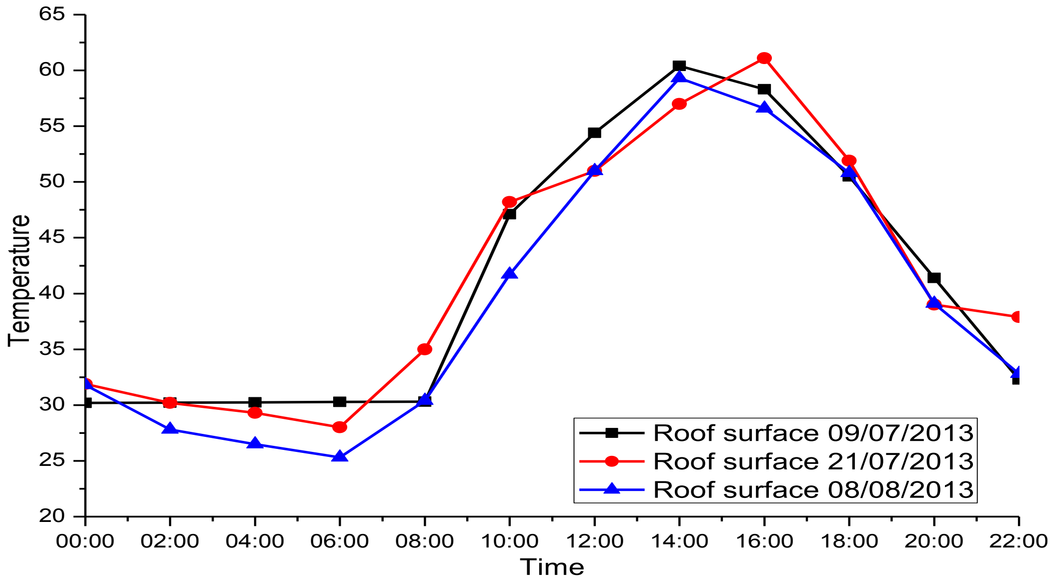

Figure 4.48 Roof surface temperature for the three days.

One of the main problems causing overheating is the absorption of solar radiation by the roof surface, as can be seen in Figure 4.49. In the middle of the day the roof surface temperature reaches 65°C and the difference between the day and night temperature approaches 30°C. However it should be noted that on the 9th of July the outside temperature and the surface temperature are stable until 08:00, and after that the outside temperature starts to rise gradually until it reaches a peak at 04:00PM and then begins to drop gradually, the roof surface temperature having jumped to 62°C within 6 hours, 32°C above the outside temperature. The same situation was repeated on the two other days, i.e. the 21st of July and the 8th of August.

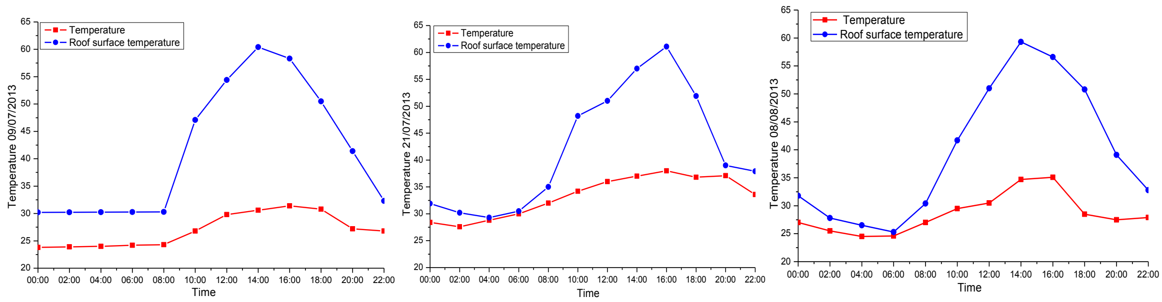

Figure 4.49 Roof surface temperature on the 9th & 21st of July and the 8th of August.

To see the full picture of the roof more clearly, and the vast difference between the air temperature and the surface temperature, Figure 4.50 illustrates this for the 45 days of study.

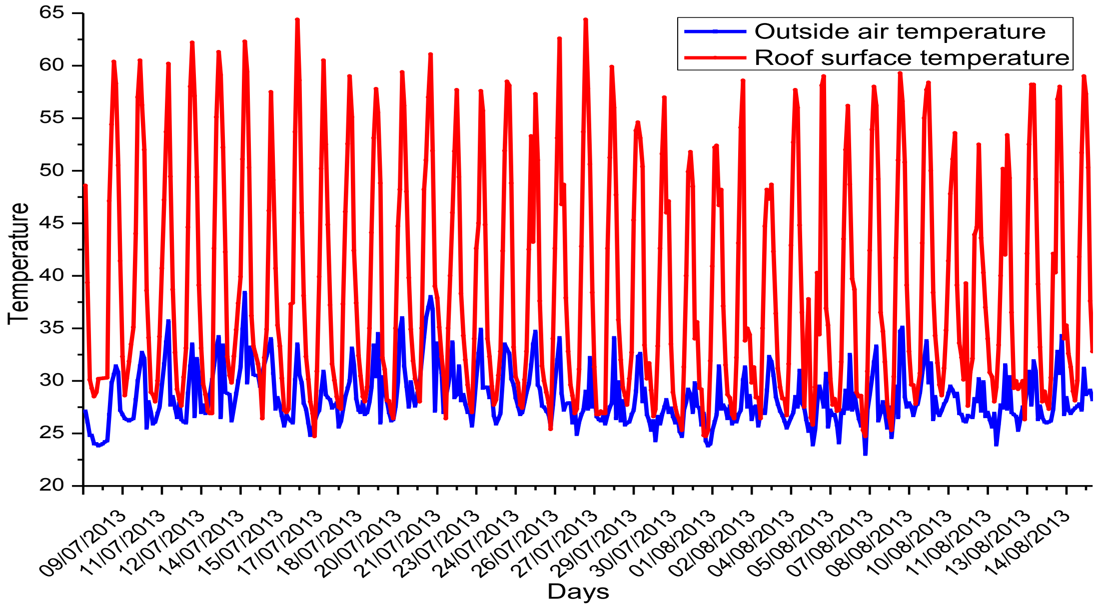

Figure 4.50 Roof surface temperature for the whole study

4.2.3 Humidity

The other part on this study investigated humidity inside and outside the building and its relationship with temperature. Figure 4.51 shows the relation of inside and outside temperature with humidity for the whole study period.

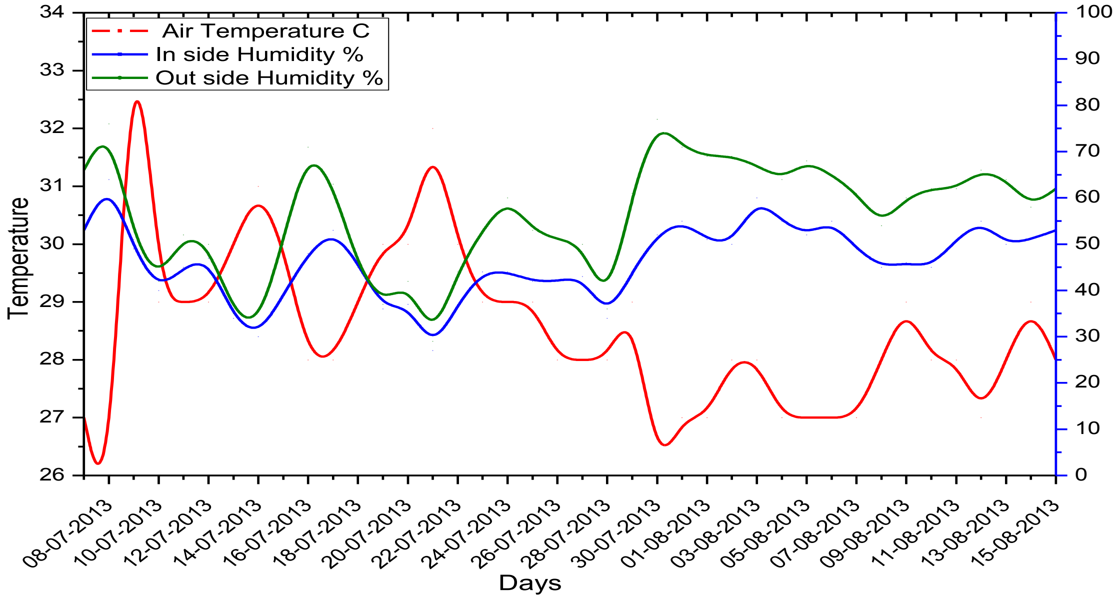

Figure 4.51 The relation between inside and outside temperature with humidity for the whole study period.

To make the situation clearer, Figure 4.52 shows the three selected days, and it is clear that there is a strong relationship between the level of moisture inside and outside, where mostly the inside humidity is less than the outside by 10%. Furthermore, there is a clear relationship between humidity and temperature.

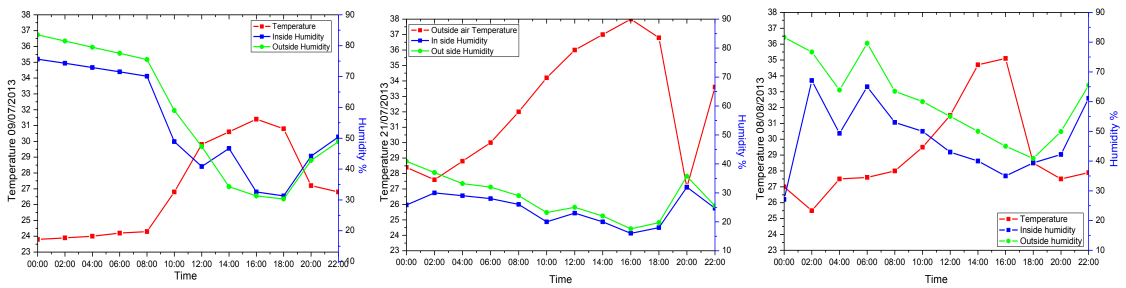

Figure 4.52 The relationship between humidity and temperature for the three selected days.

4.3 Energy consumption

The last part of this study is an investigation of the electricity consumption of the building

4.3.1 Energy consumption for flats 1 and 2

The electricity readings for flat one and two were taken together, because there is only one meter for both of them. The relationship between air temperature and energy consumption Figure 4.53 shows that electricity consumption can reach up to 350kW/h, which is extremely high for two flats.

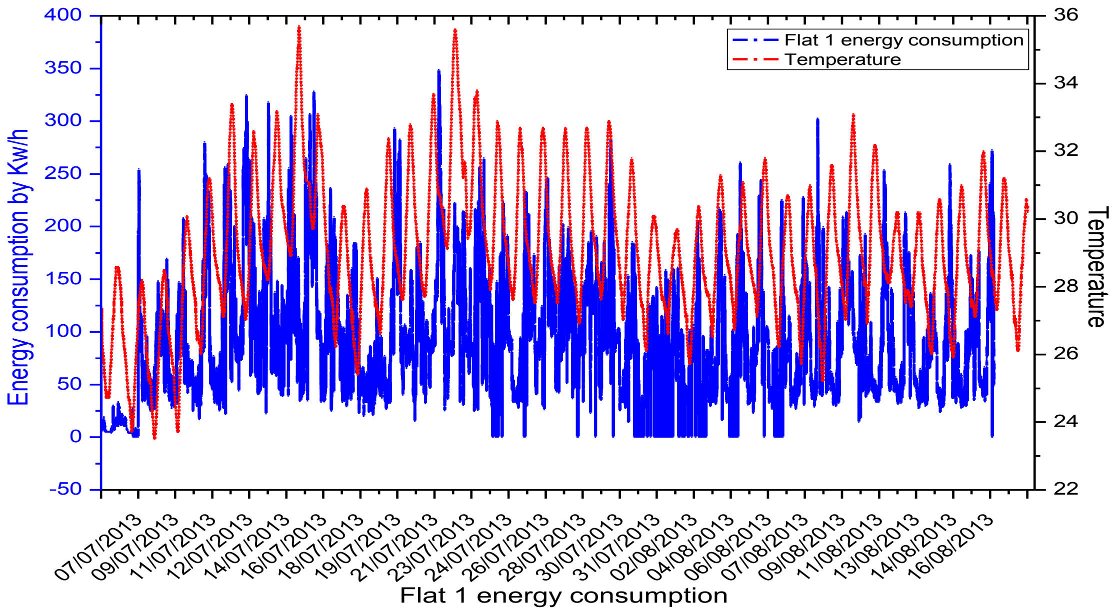

Figure 4.53 The relation between outside temperature and energy consumption/hour for the whole study for flats 1 and 2.

For more detail, Figure 4.54 shows the energy consumption on 9th of July and it is clear that energy use is increasing when the temperature is increasing until it reaches a maximum value and then starts to decrease when the temperature starts to decrease, making it clear that there is strong relationship between the temperature and the energy use.

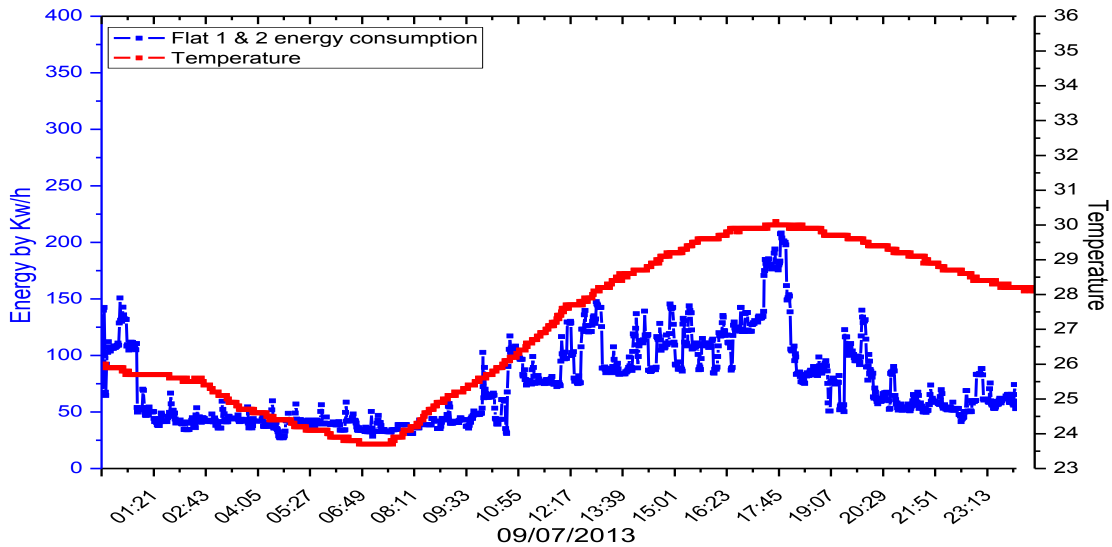

Figure 4.54 The relation between energy use and temperature on the 9th of July: flats 1&2.

Figure 4.55 confirms the relationship and shows that on the 21st of July, the hottest day, energy use is stable at around 100kW until midday, after which it starts to increase to reach 350kW, at which time temperatures are above 35°C.

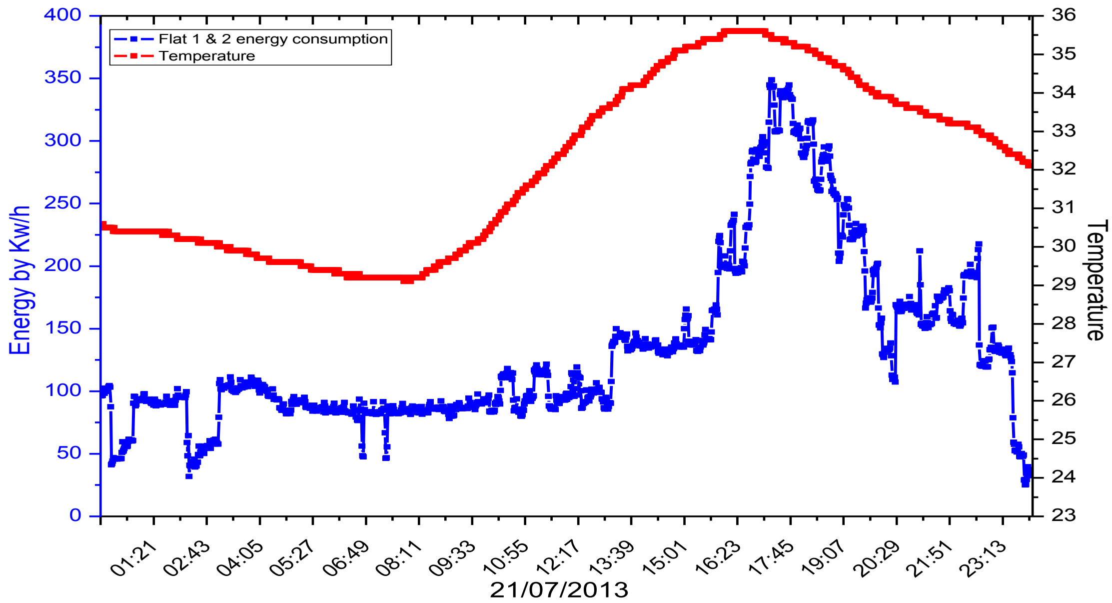

Figure 4.55 The relation between energy use and temperature on the 21st of July flats 1&2.

The last day on this study for this flat is the 8th of August, on this day the situation is different, as until midday energy use is increasing as the temperature increases but there is a drop after midday, because almost half of the flat's occupants were out for the rest of the day and energy use fell, as shown in Figure 4.56.

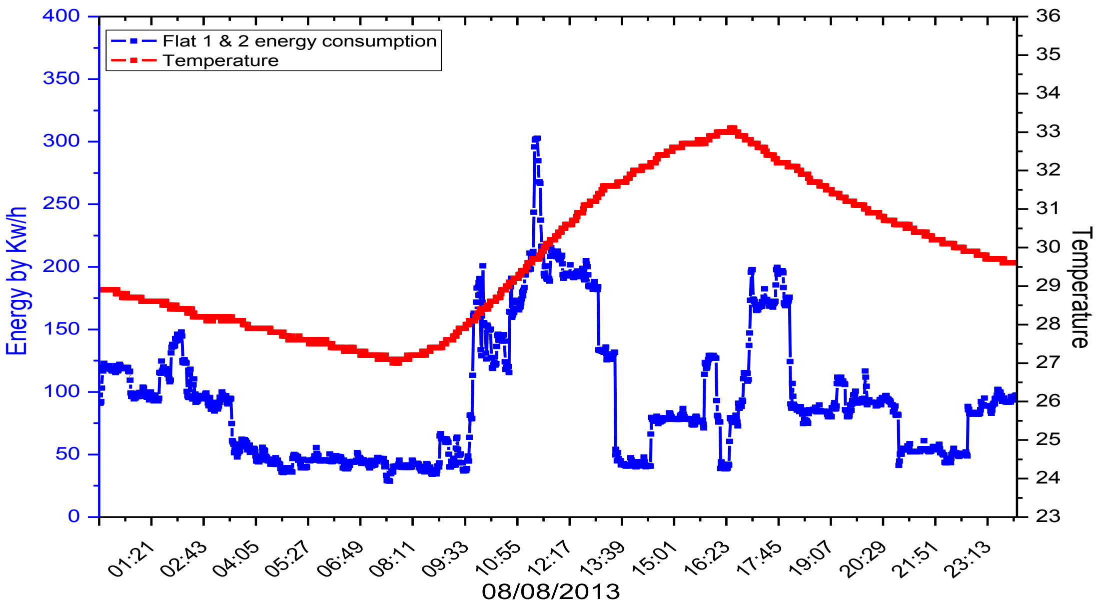

Figure 4.56 The relation between energy use and temperature on the 8th of August flats 1&2.

4.3.2 Energy consumption for flat 3

The overall picture shows that the energy use in this flat ranges between 20kW to 130kW, while the average use is around 70kW, and also that between 26th of July and the 7th of August the energy use pattern is different from the other days, which will be seen in more detail afterwards, as shown in figure 4.57.

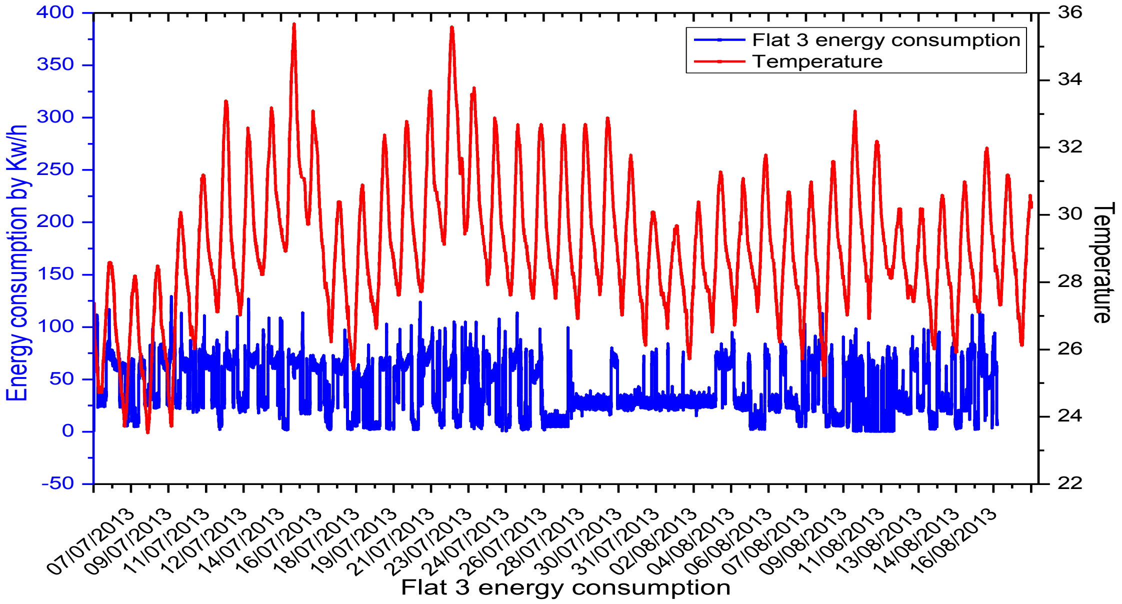

Figure 4.57 The relation between outside temperature and energy consumption for the whole study for flat 3.

Figure 4.58 shows that on the 9th of July, in the first hours of the morning the energy consumption was around 75kW, when the temperature was 26^{o}C; at 06:00 the energy drops to around 30kW while the temperature drops to 24^{o}C. At 08:00 the temperature starts to rise, followed by the energy consumption, and continues rising until 15:00, when the energy consumption falls by more than 50%, because the occupant left the flat and returned around 22:00, when the energy rose again.

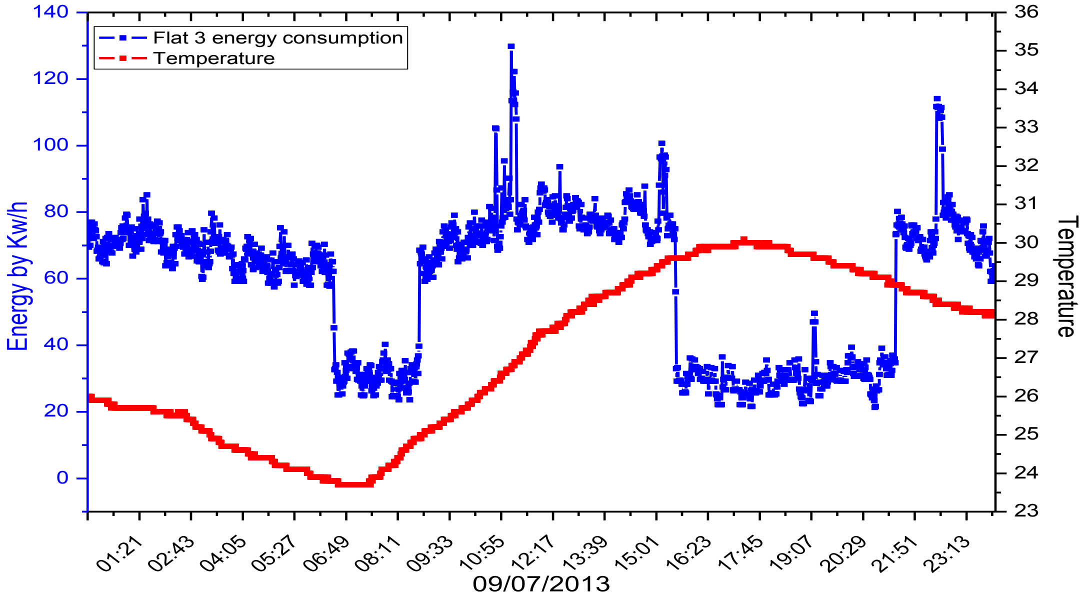

Figure 4.58 The relation between energy use and temperature on the 9th of July: flat 3.

The same situation applies on the 21st of July and it is clear that energy use starts to increase with temperature but at around 14:00 the flat became unoccupied and the energy use dropped to around 20kW Figure 4.59.

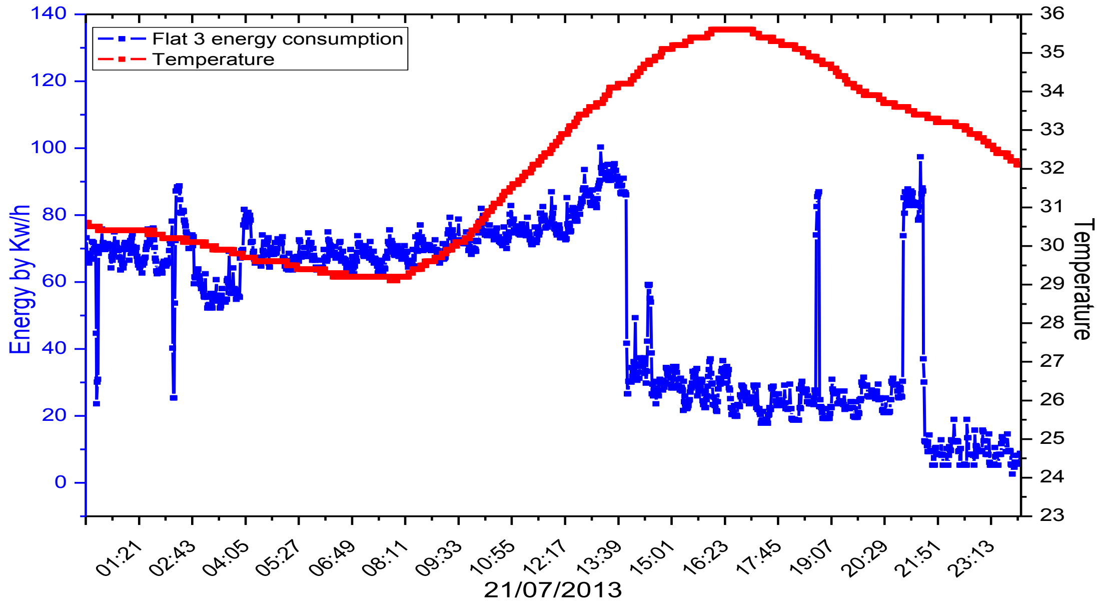

Figure 4.59 The relation between energy use and temperature on the 21st of July: flat 3.

The same situation applies on the 8th of August; in general for flat 3 it is known that it became unoccupied from 15:00 till midnight Figure 4.60.

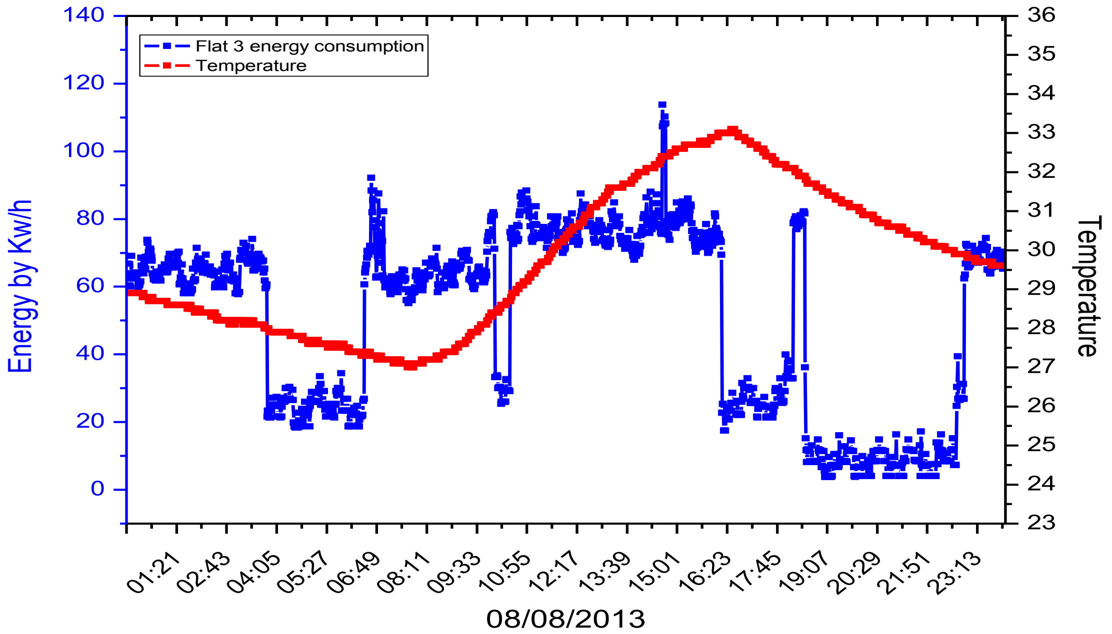

Figure 4.60 The relation between energy use and temperature on the 8th of August: flat 3.

4.3.3 Energy consumption for flat 4

The last energy consumption is for flat four, but this flat is different from the other flats because of non-use of air conditioner. Figure 4.61 shows that no matter what the temperature outside the energy consumption does not change.

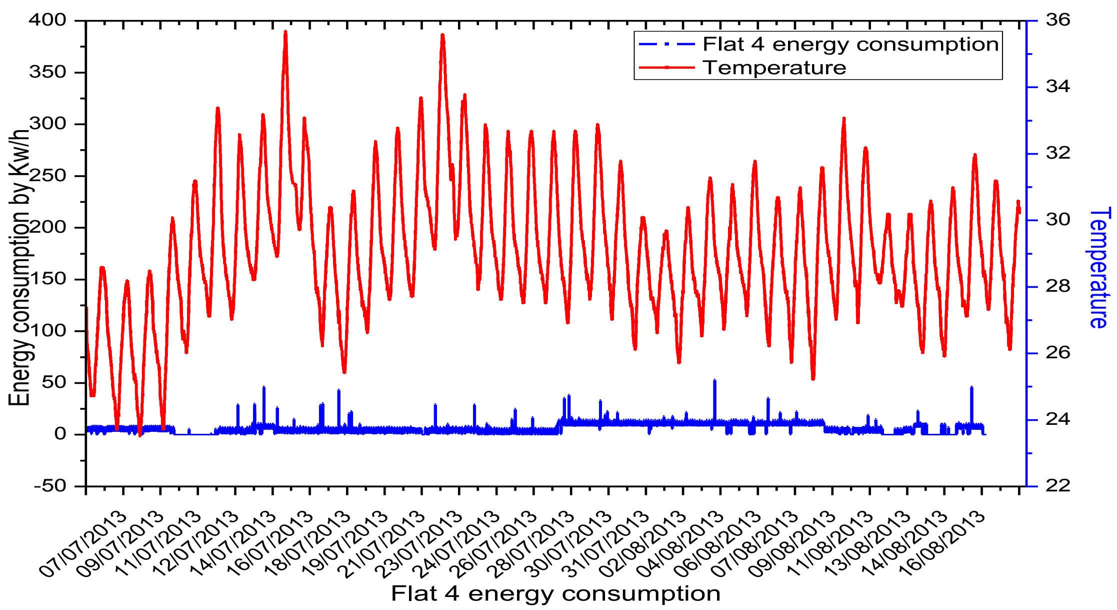

Figure 4.61 The relation between outside temperature and energy consumption for the whole study for flat 4.

To illustrate this further, Figure 4.62 shows the three days the 9th, 21st of July and the 8th of August. The difference in energy use between the maximum and minimum is only

7kW: on the 9th of July the average use was 6kW, on the 21st of July it was 5kW, and on the 8th of August 12kW.

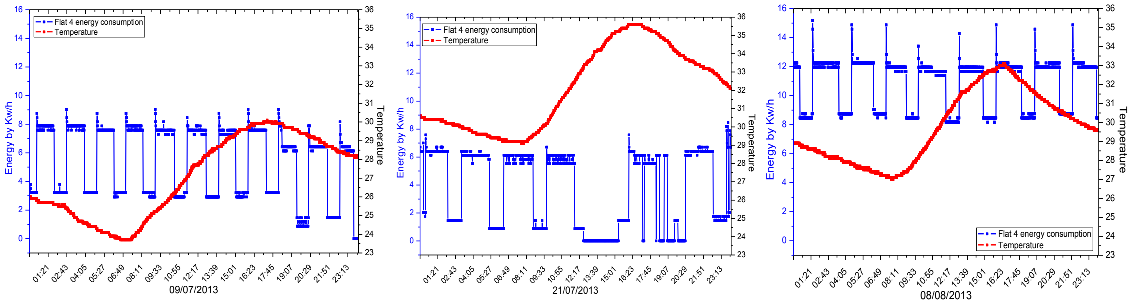

Figure 4.62 The relation between energy consumption and temperature on the 9th, 21st of July and the 8th of August for flat 4.

In general, energy use in flats 1 and 2 is stable until 09:00, after which the consumption starts to increase and can reach more than double the usage, due to the temperature increasing outside, which requires the air conditioning to be run. There are 8 conditioners in flat one and 7 in flat two, furthermore, each air conditioning unit consumes 6359W, and the consumption can reach up to 200kW, as can be seen in Figure 4.63. Most of the air-conditioner usage is in flat three late at night and it continues running until almost 02:00, presumably because of the huge heat transfer from the roof and the east surface. In flat four there is less consumption, because of the lack of air-conditioning, and it can be noted that there is a significant difference between the consumption in flats 1 & 2 and 3 and between flat 4.

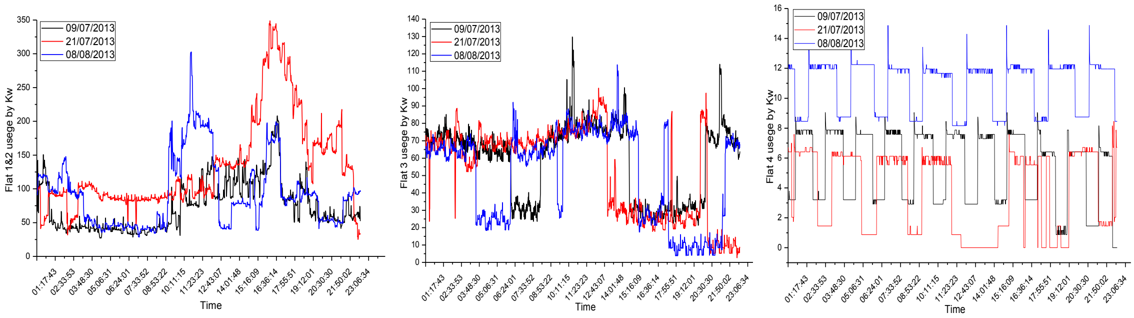

Figure 4.63 Electricity consumptions for flats 1&2, flat 3 and flat 4, on the 9th & 21th of July and the 8th of August.

4.4 Energy efficiency in buildings

Energy efficiency refers to products or systems designed to use less energy for the same or higher performance than regular products or systems. In buildings, energy efficiency means using less energy for cooling, heating, and lighting. Energy efficient buildings are designed to use less energy than traditional buildings. The objective of energy efficient design is to improve the quality of buildings and the environment. The reduction of fossil fuel based energy use is a key issue for environmental sustainability and can be greatly assisted by the more informed strategic approach of energy design at the early style.

In the early stages, design elements such as buildings orientation and configuration, choice of materials, size and location of openings, shading devices, use of natural ventilation, and lighting, must be carefully considered to ensure the building is designed to achieve energy sufficiency.

An important concept for energy in buildings is the building envelope, which is everything that separates the interior of the building from the outdoor environment, the doors, windows, walls, foundation, roof, and insulation. All the components of the building envelope need to work together to keep a building warm in the winter and cool in the summer. Different methodologies can help enhance the building envelope. Storm doors and windows can lessen the heat gain when temperatures rise. In warm areas, windows with specialised glazing can let in sunlight without heat. Indeed, even some straightforward weatherization systems, for example, weather proofing entry doors and windows, can essentially enhance the structures' energy efficiency.

Increasing the energy efficiency of buildings has become an urgent priority at the present time. In the light of rapidly depleting energy resources, energy scarcity and increasing environmental pollution, it is increasingly urgent to develop innovative ways to reduce energy consumption. The building industry is one of the largest energy consuming sectors, and significant amounts of energy are also consumed in modern buildings to maintain a comfortable environment within the building.

Energy saving and environment awareness of the building design is basically a combined path. The only option available for architectural intervention, is that construction materials and design methods used should be subjected an accurate assessment to reduce energy use, and architects should minimize the environmental degradation which might be caused by the building construction's and also achieve cost efficient results. The purpose is to reach the required comfort with the minimum input of traditional energy, by passive solar design and by using natural construction materials together with the usage of renewable power technology. This can be a target while designing the building, not only in the case of designing a new building from scratch but also when improving or altering current buildings, by incorporating efficient eco-friendly energy technologies, which dramatically reduces the building energy consumption. In general, in new structures, energy efficiency can be achieved through:

1. Bioclimatic architectural principles;
2. Load minimization by the incorporation of passive solar in building design;
3. Design of energy efficient lighting and HVAC systems;
4. Use of renewable energy systems to meet a part of the building load;
5. Use of low energy materials and energy efficient methods of construction.

It is no exaggeration to propose that these measures would lead to the buildings' energy usage decreasing by 50-75%, omitting it would yield definitely to 30% decrease. Added together, this would significantly decrease energy bills, as well as reducing the environmental effect and assisting climate change reduction, In addition, it would help to reduce the pressure suffered by many citizens in indoor situations. In fact, energy efficiency can be thought of as an unused, clean energy resource of huge potential (Clarke, 2001). Energy efficient buildings decrease both use of resources and the harmful environmental effects of pollution produced by energy construction; thus this is usually considered to be the foundation of sustainable design.

Unfortunately, the phrase *energy conservation* has negative connotations. It makes one think of shortages and discomfort. Yet architecture that conserves energy can be comfortable, humane, and aesthetically pleasing. It can also be less expensive than conventional architecture; operating costs are reduced because of lower energy bills, and first costs are often reduced because of the smaller heating and cooling equipment that is required. To avoid the negative connotations, the more positive and flexible phrases of *energy efficient design* or *energy conscious design* have been adopted to describe a concern for energy conservation in architecture. Energy conscious design yields buildings that minimize the needs for expensive, polluting, and non-renewable energy. Because of the benefit to planet earth, such design is now frequently called *sustainable* or *green*. Basic energy-saving techniques that should be used to reduce building energy use include:

1. Siting and organizing the building configuration and massing to reduce loads.
2. Reducing cooling loads by eliminating undesirable solar gain.

3. Reducing heating loads by using desirable solar heat gain.
4. Using natural light as a substitute for or complement to electrical lighting.
5. Using natural ventilation whenever possible.
6. Using more efficient cooling and heating equipment to satisfy reduced loads.
7. Using computerized building systems.

4.5 Energy codes as an international strategy for energy efficiency in buildings

Building energy standards and codes (BESC) are becoming increasingly important in energy efficiency policies. These standards can help raise concern and awareness regarding building energy use (Vijayalaxmi, 2010) thus helping to ensure that new buildings will be built to a minimum level of energy sufficiency. These codes are aimed to provide a degree of control over building design practices and raise architects' consciousness of energy aware design in building which can improve building energy performance (Iwaro & Mwasha, 2010).

4.6 The need for a Libyan energy efficiency building code

Energy efficiency in building in Libya receives little attention. Buildings are designed without any consideration to energy use and the environment; there are not even any direct codes or norms for climate sensitive design in terms of building materials. It all lies in the hands of the designer (Built and Natural Environment Research Papers, 2011). However, a serious estimation would suggest that most of the recent buildings are not planned keeping in consideration local climatic situations. Huge use of concrete and glass, high levels of lighting and heavy dependence on space cooling and air conditioning machines are a common feature of Libyan buildings. The use of these features means these buildings need extra energy to be made comfortable their occupants. Today's buildings in Libya are very energy intensive because they rely too much on mechanical and electrical systems for cooling, heating, and lighting. Traditional buildings, on the other hand, used tiny amounts of energy for cooling, heating, and lighting, and the energy they did use was natural and renewable. Because modern buildings use about 35% of all the countries' energy consumption, as mentioned above, they are a main reason of energy depletion, pollution, and global warming. More effective mechanical and electrical systems are not the chief way of reducing the energy consumption of buildings. It is the design of the building itself that will have the extreme effect on minimising the energy requirements of buildings. For instance, current buildings hardly use shading devices, while traditional building regularly did.

Although a building code of Libya exists, it does not address this issue. Therefore, regarding the residential sector, an important step is to develop Libyan energy standards. The application of average energy will help to adapt buildings to the different climates found in Libya and therefor contribute to a reduced rate of growth in energy demand. This will make sure that the designs of new residential buildings are energy efficient.

To achieve energy efficiency and defend our environment, it is significant for Libya to encourage energy efficiency; a residential building code is the first stage towards this objective.

4.7 Climatic analysis of the building located in Tripoli city Libya

4.7.1 Geography of Libya:

Tripoli city lies on the far north of the continent of Africa overlooking the Mediterranean See figure 4.64. The ordinates of the city are latitude 32^{o} 47” N and longitude 13^{o} 04” E respectively. Tripoli is classified as a hot dry climate, this type of climate usually being found at latitudes between 20° and 35°, and the main shelter issue is overheating. The mean summer temperatures are around 25^{o}C but can reach a maximum of 45^{o}C; clear nocturnal skies can cool temperatures down to as low as -10°C.

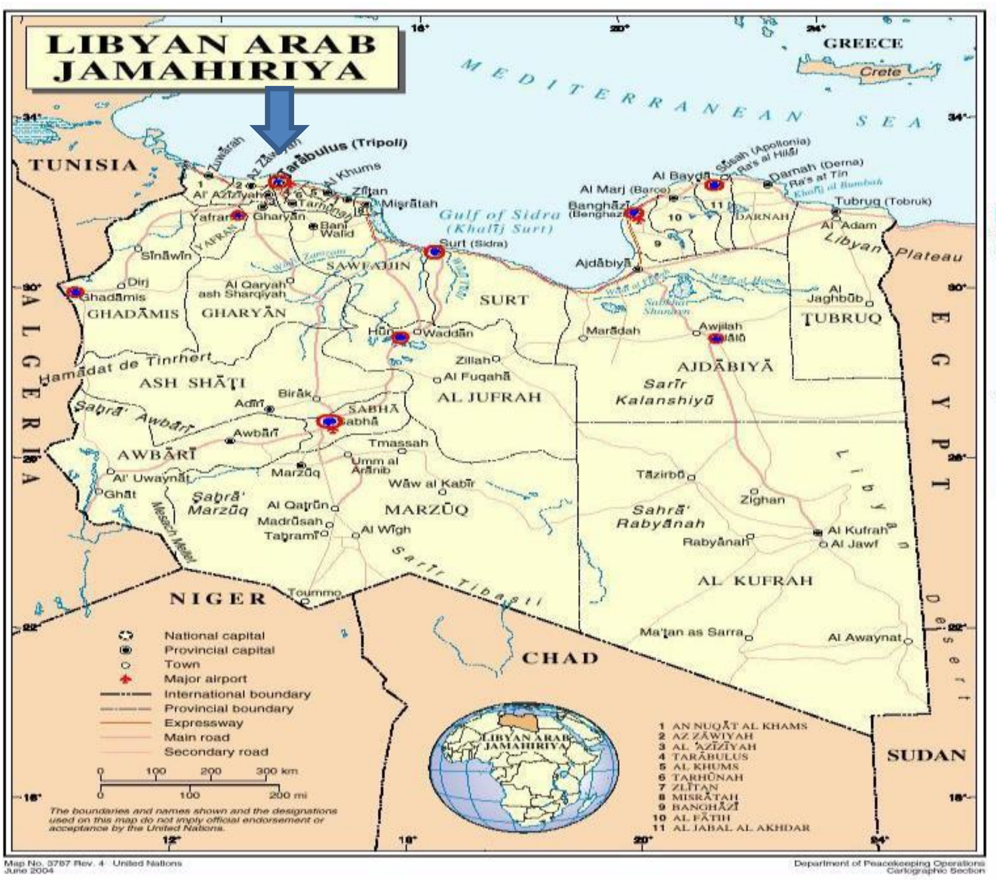

Figure 4.64 Position of Tripoli on the map.

4.7.2 General characteristics of climate in Libya:

There are sharp local contrasts in climatic conditions in Libya. The most striking feature of the climate in Libya is the contrast of sea and desert, between the humid Mediterranean coast and the arid desert regions.

Libya is included in the Mediterranean region, which extends to the north of it, in summer characterized by warm dry conditions and cool and wet in winter. Most Libyan cities have hot dry summers and cold winters. This region is marked by high daily temperature differences.

Summer (June to August) is normally hot and dry, consequently summer weather features are clear sky, no precipitation and high temperature. Winter (December to February) is notably a cool, rainy and there is cloudiness in this season. Spring and autumn are relatively shorter in their duration. The building studied is located in the city of Tripoli, which is only 21Km north of the area where the hottest air temperature ever was recorded, 58°C, (Hocine & Sharples, 2010). Table 4.1 shows the yearly average weather condition readings covering rain, average maximum daily temperature and average minimum temperature.

Table 4.1 Ambient temperature in Tripoli

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Record high °C	28	33	38	41	43	44	46	44	45	41	36	31
Average high °C	16	17	19	22	24	27	29	30	29	27	23	18
Average low °C	8	9	11	14	16	19	22	22	22	18	14	9
Record low °C	1	3	4	6	6	10	16	17	15	10	6	1
Rain mm	81	46	28	10	5	0	0	0	10	41	66	94

Using the Autodesk Ecotect analysis tool software the building location was studied in more detail for better understanding.

4.8 Modelling

The building model was built, and located with the accurate position of latitude 32^{o}47’.63” N and longitude 13^{o}04’21.07” E as in figure 4.65.

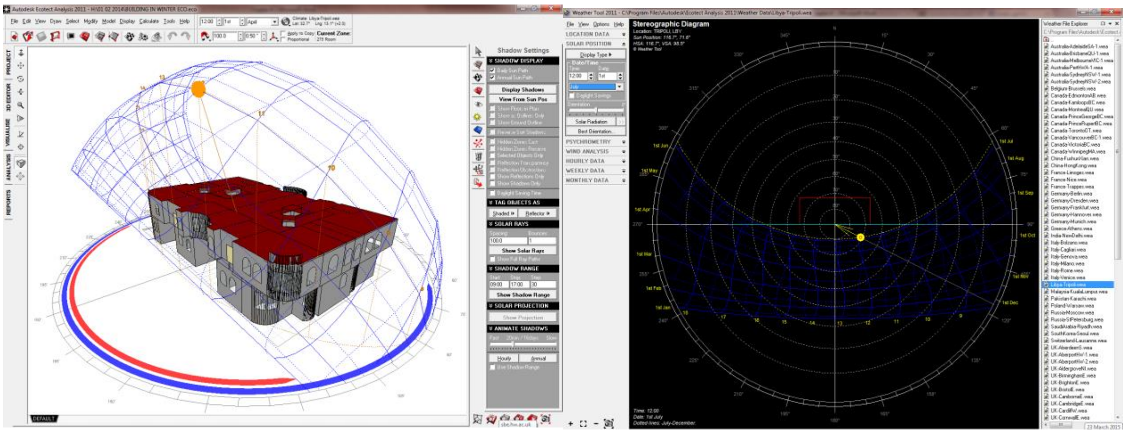

Figure 4.65 Modelling the building.

4.9 Sun path

With respect to the Tripoli sun path, it is to be noted that in summer the sun rises from the north-east and sets in the north-west, as can be seen in Figure 4.66, while in winter the sun rises from the south east and sets in the south west. Understanding this helps to guide the best design of the building.

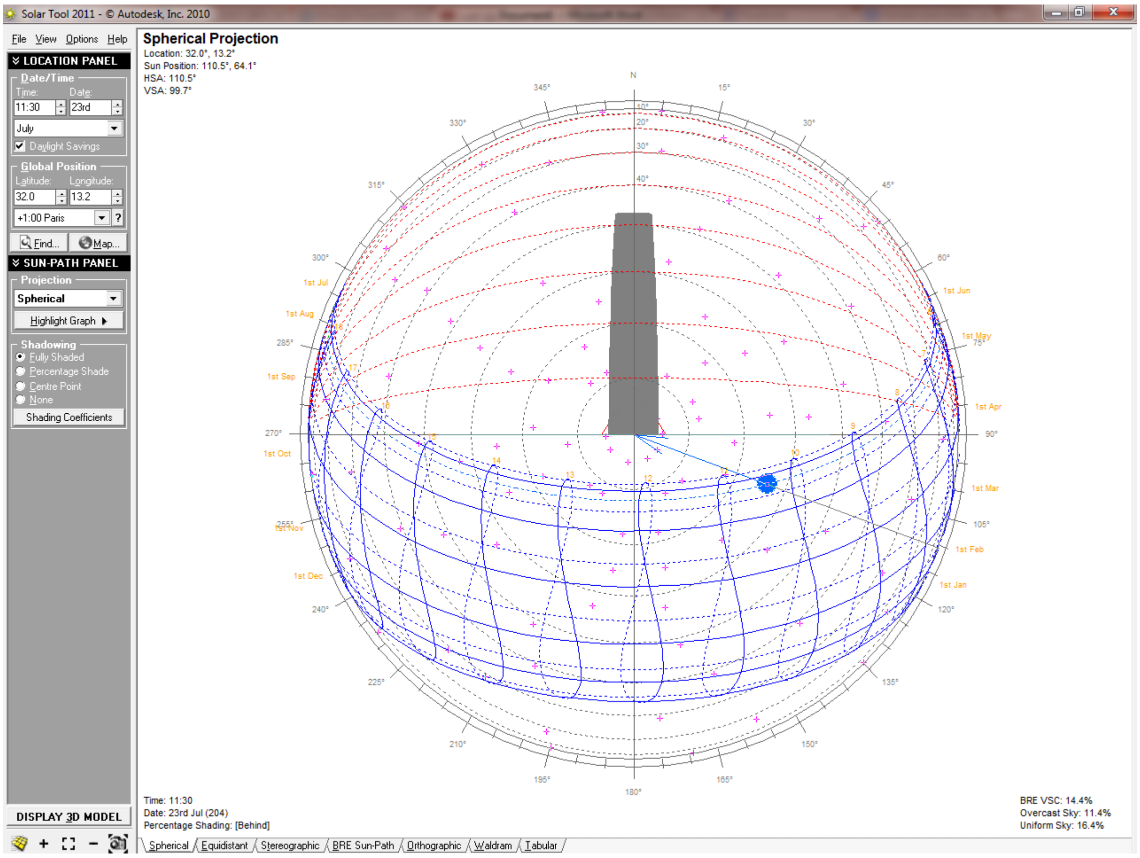

Figure 4.66 Sun path of the building.

4.10 Orientation

Using Ecotect analysis software can also help to find the best orientation; for this building it shows that the best orientation is 187.5^{o} north. Moreover, it can also show the overheating period, and it indicated that the east and west sides are the area's most prone to overheating, as shown in Figure 4.67.

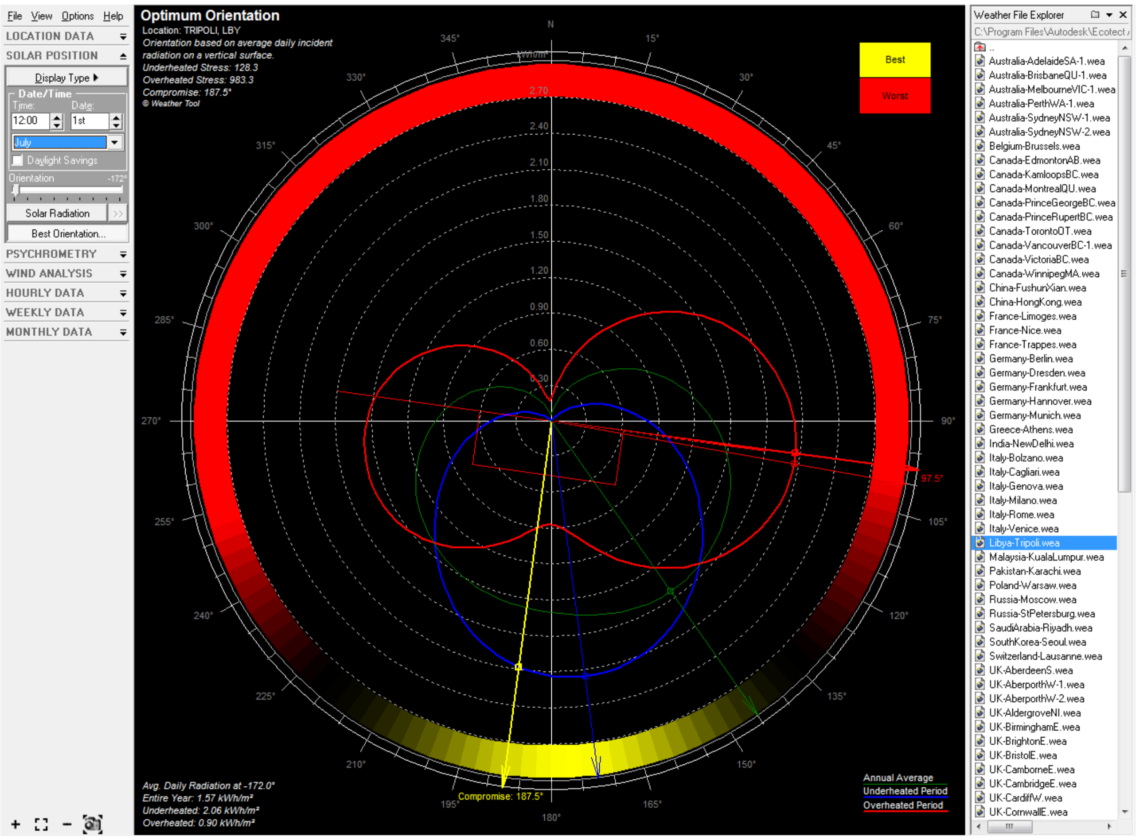

Figure 4.67 The best building orientation

4.11 Monthly diurnal averages

Figure 4.68 shows monthly diurnal averages for this location, and it shows also the relationship between temperatures, direct solar gain, humidity, and wind speed on the 21st of July. It is clear that the temperature on that day is above 42°C, while the direct solar gain at 14:00 reaches a peak, the other noticeable point being that the humidity is in inverse relationship with the temperature.

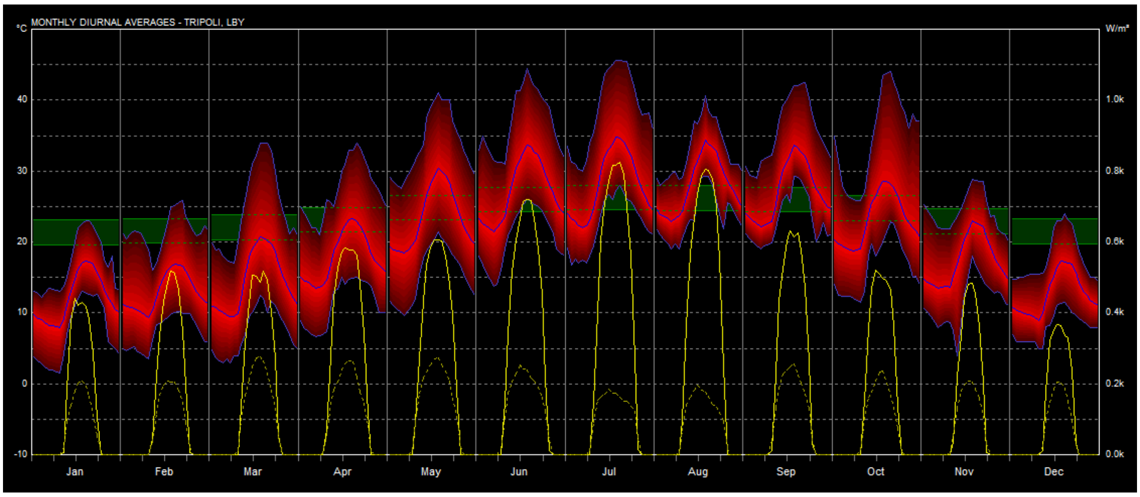

Figure 4.68 Monthly diurnal temperature averages.

4.12 Wind direction

Wind direction and its temperature is one of the important issues that can help to cool the building through natural ventilation, but it can also deter people from opening the windows, especially if the wind is laden with dust or it is hot. The prevailing wind direction and its speed for the whole year at 09:00 and 15:00 in all directions, this feature is very useful for designers it can help to choose the openings direction and size.

4.13 Cooling degree

Figure 4.69 clarifies the cooling degree hours, heating degree hours, and solar excess degree hours, it is clear that from the end of April cooling degree hours increase to reach a peak in July and starts to fall to the end of October, and the opposite to heating degree hours.

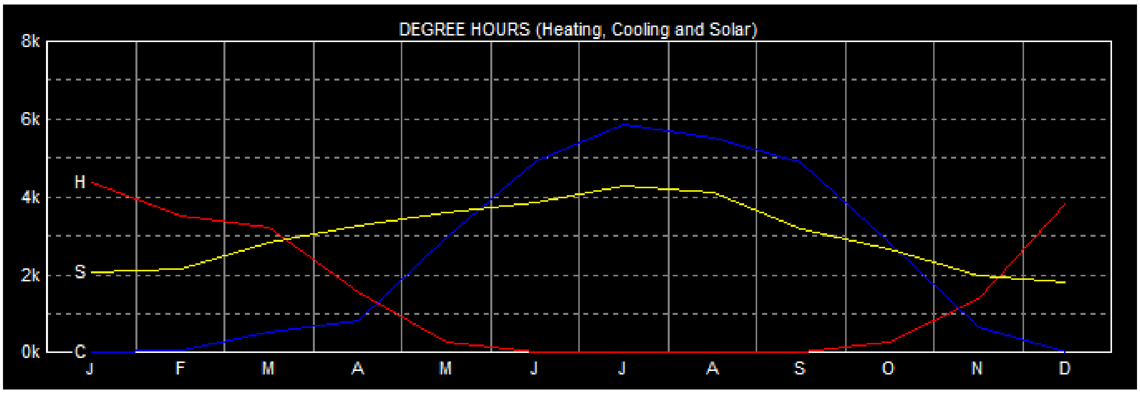

Figure 4.69 Cooling degree hours.

4.14 Psychrometric chart

The comfort range analysis was obtained through the psychrometric chart, where the yearly average comfort zone was found to be with the air temperature range within 20^{o}C to25^{o}C, and the relative humidity within the range 20% to 80%. The comfort zone are plotted as shown in figure 4.70

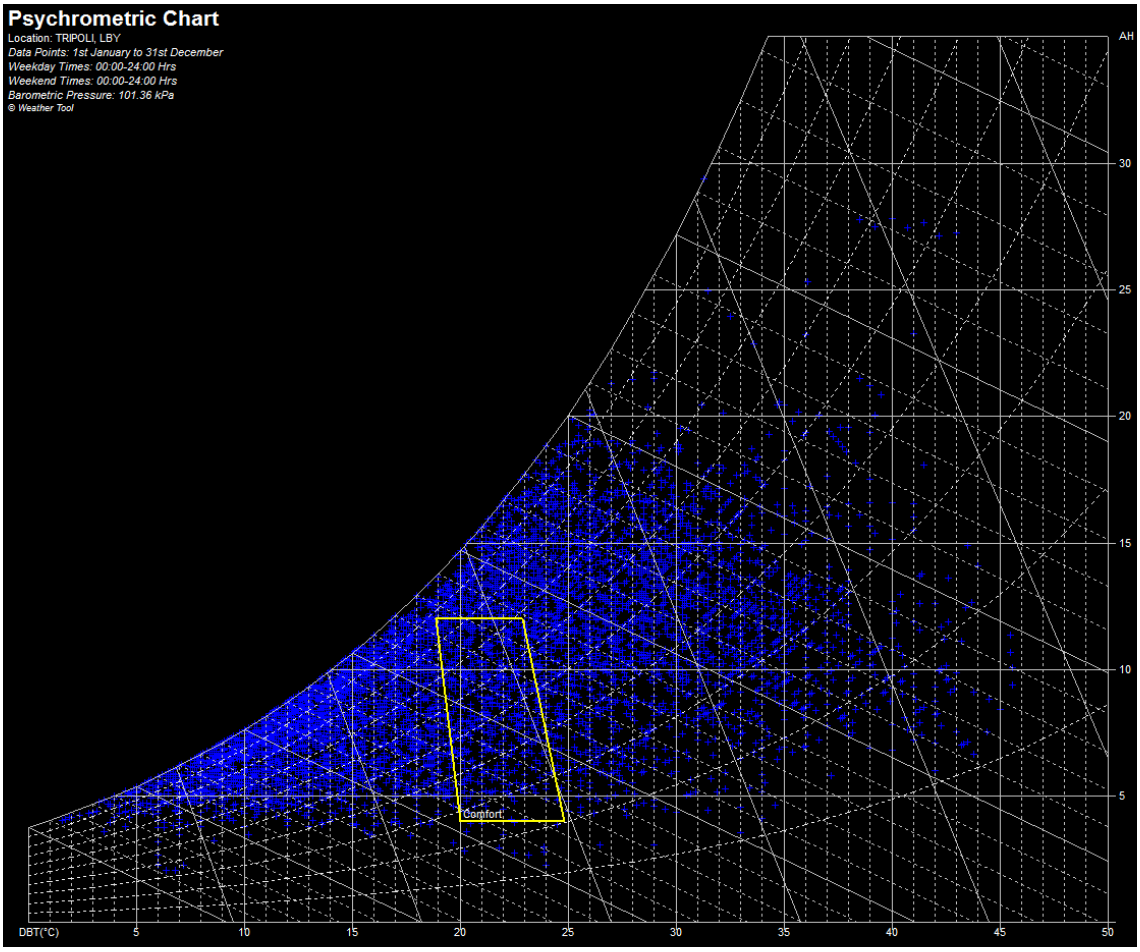

Figure 4.70 Psychrometric chart.

To understand the overall climate classification Figure 4.71 shows the chart overlay frequency of the zones; cool zone temperature is between 15^{o}C to 20^{o}C, and humidity between 40% to 70%; moderate zone temperature is between 20^{o}C to 27^{o}C and humidity between 20% to 70%; warm dry and warm humid zone temperature is between 27^{o}C to 33^{o}C, while the humidity for the warm dry zone is between 20% to 50%, and the warm humid between 50% to 80%, hot dry zone temperature between 33^{o}C to 43^{o}C and humidity temperature is between 10% to 40%, the last zone is the hot humid temperature between 33^{o}C to 40^{o}C and humidity of 30% to 65%.

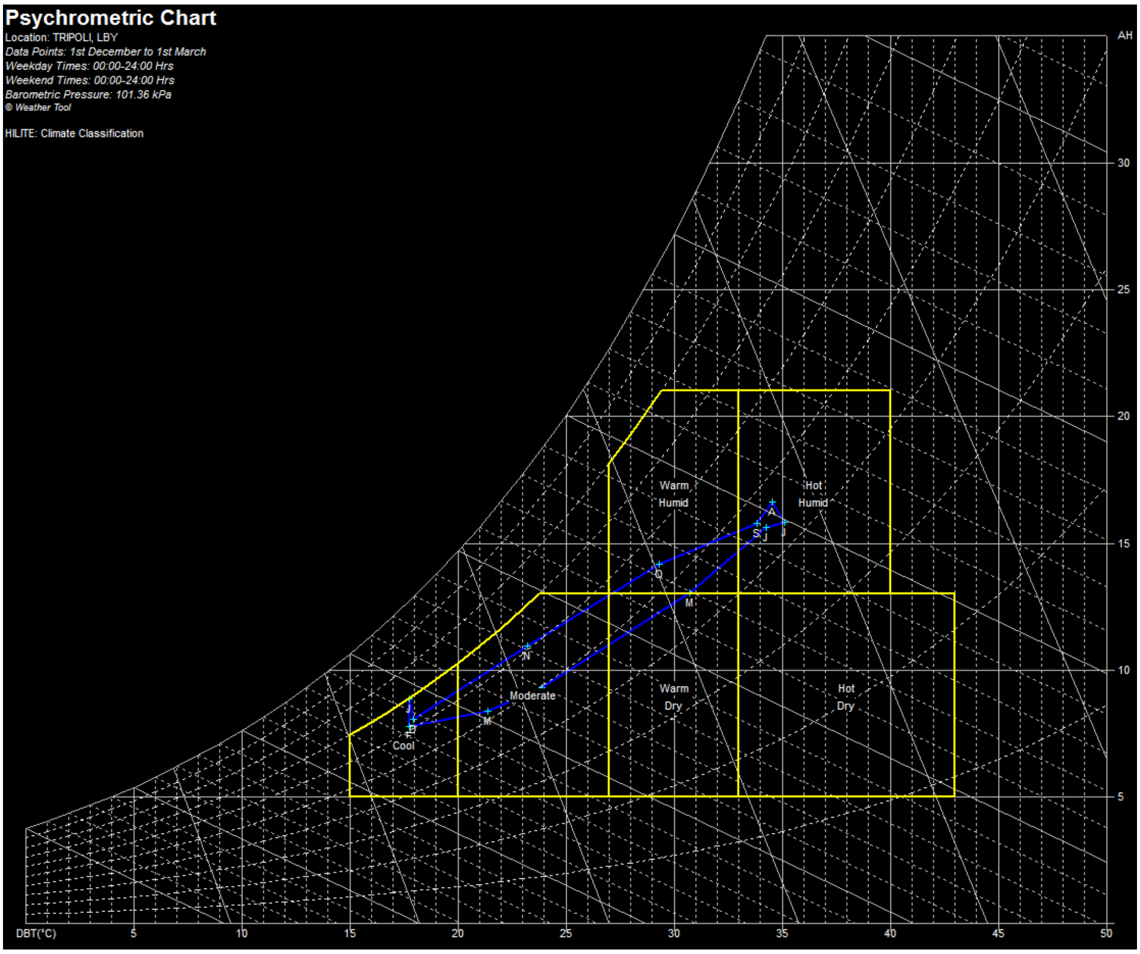

Figure 4.71 Chart overlay frequency of the six zones.

To illustrate more details, the chart was divided into two seasons, summer and winter with more specific details of design techniques. Table 4.2 shows the comfort zone ranges of temperature and humidity in the summer and winter seasons based on a combination of multiple passive heating and cooling techniques such as passive solar heating, thermal mass effects, exposed mass (night ventilation). This will combine their effects to form a comfort zone on the graph. Figure 4.72 shows a comparison based on the effects of natural ventilation, direct evaporative cooling, and indirect evaporative cooling.

Table 4.2 Summer and winter seasons.

#	passive techniques	Summer season		Winter season	
		Temperature ^{o}C	Humidity %	Temperature ^{o}C	Humidity %
1	Passive solar heating	17-23	0-12	12-17.5	0-100
2	Thermal mass effects	16-35.5	10-75	11.5-29	20-90
3	Exposed mass + night ventilation	16-40.5	10-75	11.5-34.5	10-90
4	Natural ventilation	23-32	15-90	17.5-26	20-90
5	Direct evaporative cooling	23-36	0-60	17.5-31	0-80
6	Indirect evaporative cooling	22-39	0-75	17.5-34	0-90

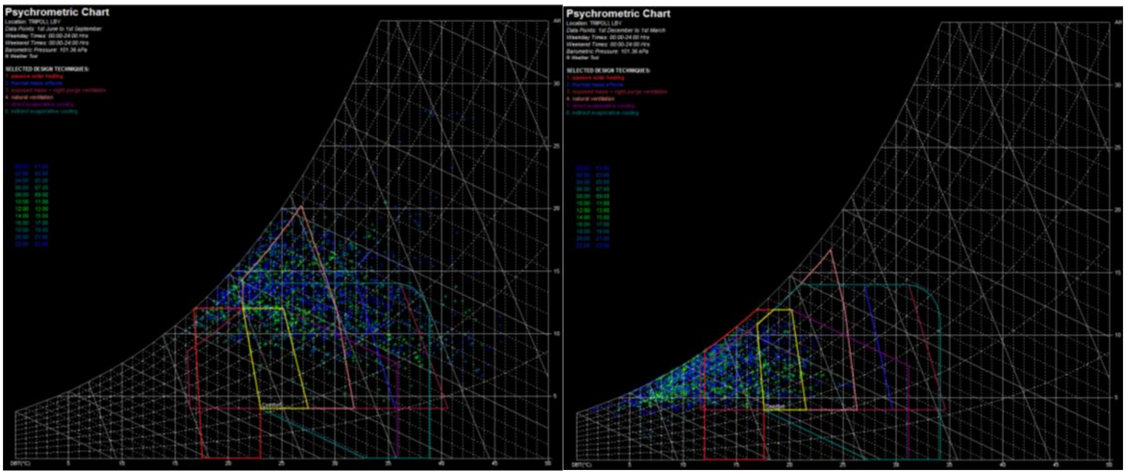

Figure 4.72 Comparison charts between comfort zone in summer and winter seasons.

4.15 Site features

4.15.1 Weekly temperature summary

Each item will be studied separately, Figure 4.73 show the relation between temperatures, hours of the day, and the year by weeks. It is clear that for the whole year, from 08:00 temperature start to rise until 14:00, the other issue is that summer time is the hottest and temperature is above 40^{o}C.

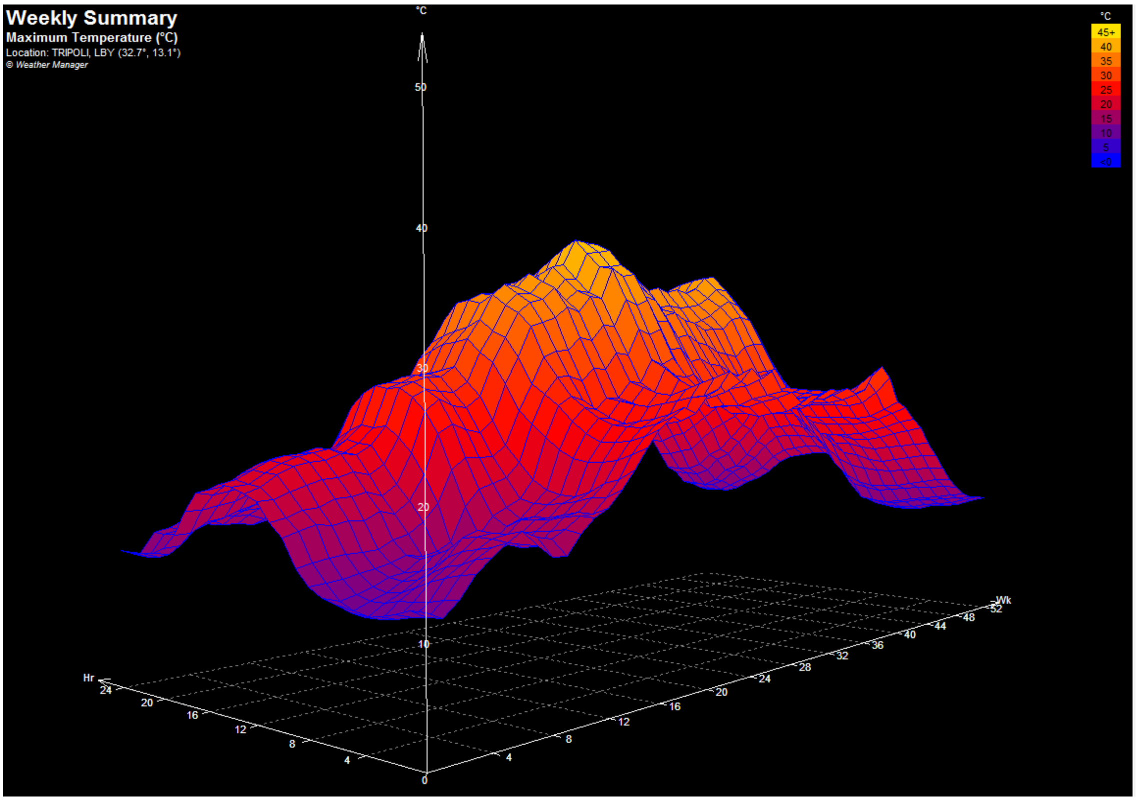

Figure 4.73 Weekly temperature summaries.

4.15.2 Weekly humidity summary

Figure 4.74 shows that humidity is high during the early morning and evening and lowest in the middle of the day due to the high temperature.

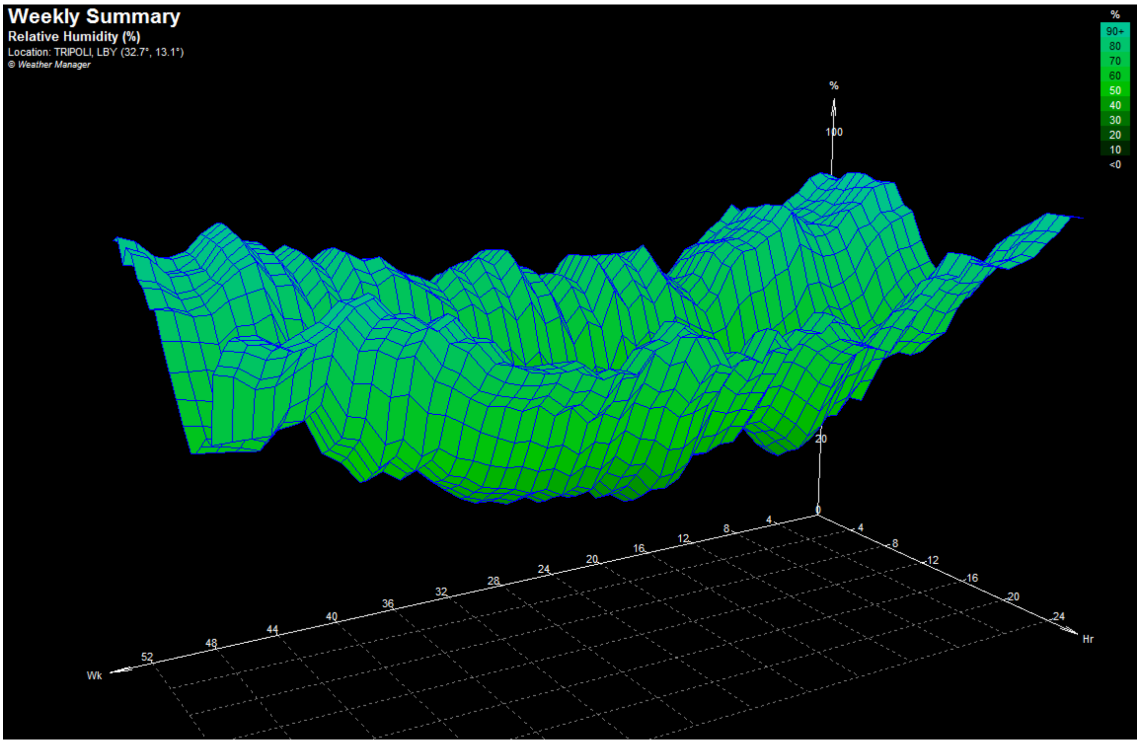

Figure 4.74 Weekly humidity summaries.

4.15.3 Weekly solar gain summary

The solar gain is not less important than temperature and humidity, as the buildings absorbs the heat and transfers it to the inside of the building. Figure 4.75 indicates that the building starts to absorb the direct solar gain from 8am and this continues until 6pm. It also indicates that the worst time for solar gain is during week 24, where it reaches up to 900W/m^2.

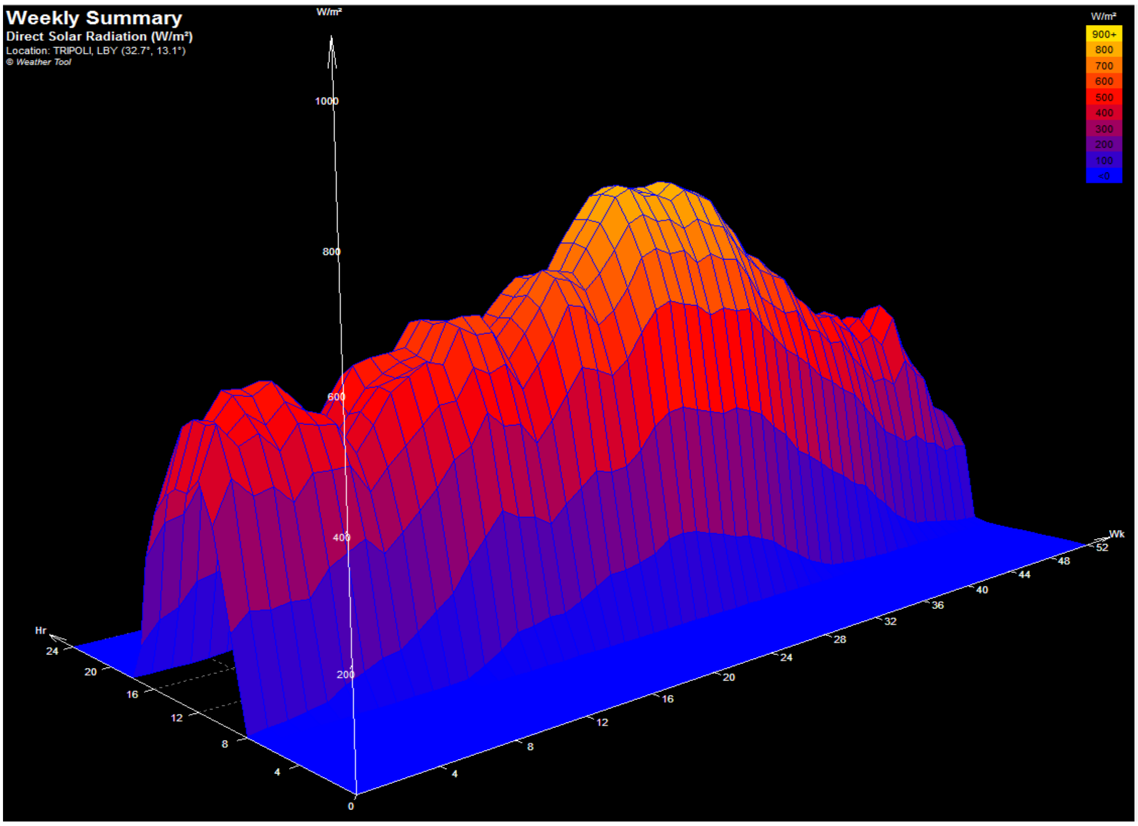

Figure 4.75 Weekly solar gain summaries.

4.16 Conclusion

This chapter leads to the following conclusions:

- Results showed that 90% of the residents use air conditioners to cool their houses, but at the same time they pay a very small amount for their energy. This is due to two possibilities, first the energy is too cheap and the second is that, although it is low-priced, they may by-pass the electricity meter.
- 70% of the houses are 200m^2 and 75% of them built using concrete bricks.
- 63% use the air conditioner for heating in winter.

- Rooms located on the east side warm up from early morning until midday, while rooms located on the west side start to warm up after midday until sunset. Moreover, the first floor is warmer than the ground floor.
- The roof absorbs solar gain all day and as a result of this the surface temperature can reach up to 69^{o}C. For this reason the roof temperature is always above the air temperature, which has a negative impact on the first floor temperatures.
- The basement temperature changes very little no matter what the outside temperature.
- The north and south façades behave similarly and their temperatures are consistent and in harmony with the air temperature.
- There is a strong relationship between temperature and humidity: the higher the temperature the more humidity is decreases and vice versa.
- There is a very strong relationship between electricity consumption and temperature: all indicators indicate that the higher temperatures increased electricity consumption, although it is not clear how well the cooling availability is matched to the load. This can lead to difficulties in modelling the performance of the building, as it is generally assumed in such models that the cooling output will increase incrementally to meet the load exactly. In practice the situation is more complex than this.

- Concern about local and global environmental issues is growing over both the developed and the developing world. Global warming, ozone depletion and destruction of natural habitats are the cause of serious debate in international forums.
- There is a basic linkage between the buildings and the environment. High levels of energy use in buildings can have serious environmental impacts such as global warming, air pollution and ozone depletion. These effects are not limited to the local or direct environment surrounding the buildings but include regional and global effects, and there are many possible strategies and policies to deal with such negative impacts. In Libya, concern about these issues is growing, and the government needs to introduce new techniques to reduce energy consumption in residential buildings by any possible means.
- The main gas responsible for climate is CO_2 and thus reducing emissions of CO_2 and other GHG_s is one of the biggest environmental challenges facing the world

as it seeks to achieve sustainable development. Although developed countries have undertaken to reduce CO_2 emissions, consumption is still increasing year by year.

- The previously mentioned dramatically impact on the environment is directly the result of decisions made by architects. Architects have the opportunity and responsibility to make a major contribution to human welfare through carbon dioxide control, so designers should be conscious of the environmental impact of their decisions. There is a clear need to further develop our knowledge, methods, tools and solutions, principally in relation to the planning and design of buildings in severe local climates, to ensure low energy buildings in the future.
- Sustainability in the field of energy has to be approached at two levels, the first being energy efficiency, and the second being the use of renewable energy sources. Improving energy efficiency in buildings is one of the most cost effective ways of reducing emissions and protecting the environment. Providing renewable energy technologies to developing countries is the best way to deal with local pollution problems and to minimize emissions.
- There is a growing trend around the word to develop and introduce performance based building energy codes which give designers greater flexibility. Experience in some countries indicates that the performance based approach in building energy codes is important for promoting innovation and new techniques in energy efficiency design. Moreover, an energy performance criterion gives designers greater flexibility, as it helps to reduce the restrictions of the prescriptive criteria which are generally used in current building control codes.

- To achieve energy sustainability and protect our environment, it is important for Libya to promote energy efficiency and control energy consumption in its buildings. The energy efficiency building code is the first step towards this objective, however it needs to be established what would be the most effective code for the Libyan context.

The theory of this thesis is that the use of appropriate orientation, materials and building configuration would offer suitable solutions for energy and environmental problems in hot arid countries. This hypothesis is to be examined through an example located in Libya. A domestic building in Libya was studied with a view to reducing its energy consumption. The study included detailed monitoring, followed by computer simulation of a range of intervention strategies.

5 Chapter 5 Questionnaire results and discussions

5.1 Introduction

This chapter discusses the methodology used in the thesis. It contains descriptions of methods used to survey the case study building, measurements and data collection. Based on the earlier analysis of different tools it was established that the best design and evaluation tool to be used is a computer program. Results were validated by comparison with field data taken from the case study residential building.

Buildings, in addition to offering shelter and fulfilling aesthetic requirements, should provide conditions of comfort for their occupants. During summer, especially in hot climate regions, buildings are exposed to high intensities of solar gain, which may result in over-heating, causing discomfort to the users. Under these conditions, cooling the building is very important. Cooling processes can include diverse measures from simple natural cooling techniques, evaporative cooling and natural ventilation, to mechanical cooling systems, i.e. air conditioners. (Asimakopoulos & Santamouris, 1996). There is a trade-off which depends on the relative heating and cooling stresses in the environment. In a very hot climate, as in Tripoli, solar gains in winter may not be needed, whereas in a very cold climate solar gains even in summer may be desirable.

Part of all building designs and are known as "passive cooling". As explained in Chapter 2, by engaging passive cooling techniques in new buildings, the designer can often eliminate the need for mechanical cooling or at least reduce the size and cost of the equipment. The two important ideas in any passive cooling design are the elimination of unwanted heat gains, including direct solar radiation from outside, ventilation, and internal gains from the residence, and the creation of cooling.

This work presents part of a larger research programme whose overall aim is to study the thermal performance of domestic buildings in Tripoli, with a view to reducing the cooling load and energy consumption.

The first part presents the results of the questionnaire that was developed with the help of specialists in this field by SPSS software. The second part presents analysis of internal data, consisting of data from sensors located inside the building recording temperature, humidity and electricity consumption between 05/07/2013 and 16/08/2013. The third part presents analysis of external data, i.e. external surface temperatures of the building, temperature readings for the four facades, which were taken every two hours throughout the day and for walls and glazing for each floor, using an infra-red camera. In a later part of the work, a detailed computer simulation of the thermal performance was carried out, in order to determine strategies to reduce the energy load.

5.2 Analysis and data results

5.2.1 Questionnaire results

To build up a general picture of the kind of buildings in Tripoli-Libya, a questionnaire was distributed see appendixes A.

The questionnaires were distributed to 145 people with various ages and gender. This was to enable the researcher understand perception of the target group about thermal comfort and climate change through the questionnaire. Data collected through the questionnaires was entered and analysed using IBM SPSS Statistics - Predictive Analytics Software. The IBM SPSS Data Collection suite is a software product that helps those conducting surveys and market researchers to gain a deeper understanding of people's attitudes, preferences and opinions. It also helps throughout the entire research process—thus, from survey design, data collection, data management and ensures clear timely reporting of the analysed data. Due to the large amount of data collected, the relevant and important data needed for the research objectives were selected and the results are as follows.

Figure 6.1 shows the age and gender distribution of the respondents. Between the ages of 20-30 years females had the highest percentages (24.26%) while their male counterparts in the same age group had only 26.47%. On the other hand, between the ages of 30-40 years females of ages the percentage of females was only 2.21% whereas 28.68% were males recorded. Therefore, overall, the number of males dominated the number of females.

5.2.2 Thermal comfort

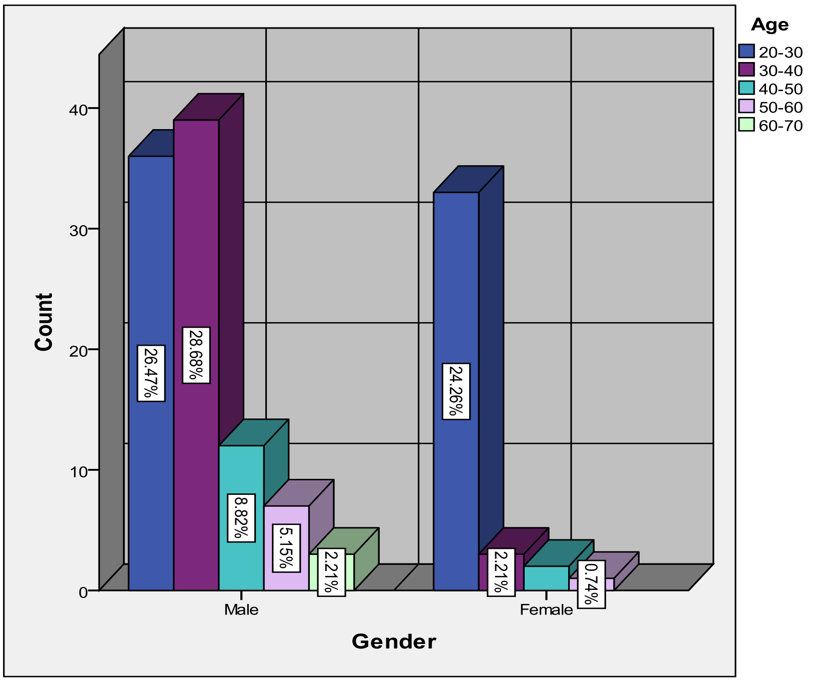

Figure 5.1 The relation between age and gender

The important question is the degree of satisfaction with the thermal comfort of the house in relation with the age. As can be seen in Figure 6.2, 27.5% of those who answered that they were not satisfied were aged 20-30, followed by those aged 30-40, with 15%. However, the percentage of respondents who were satisfied was 23% of those aged from 20-30 and 15% of those aged 30-40.

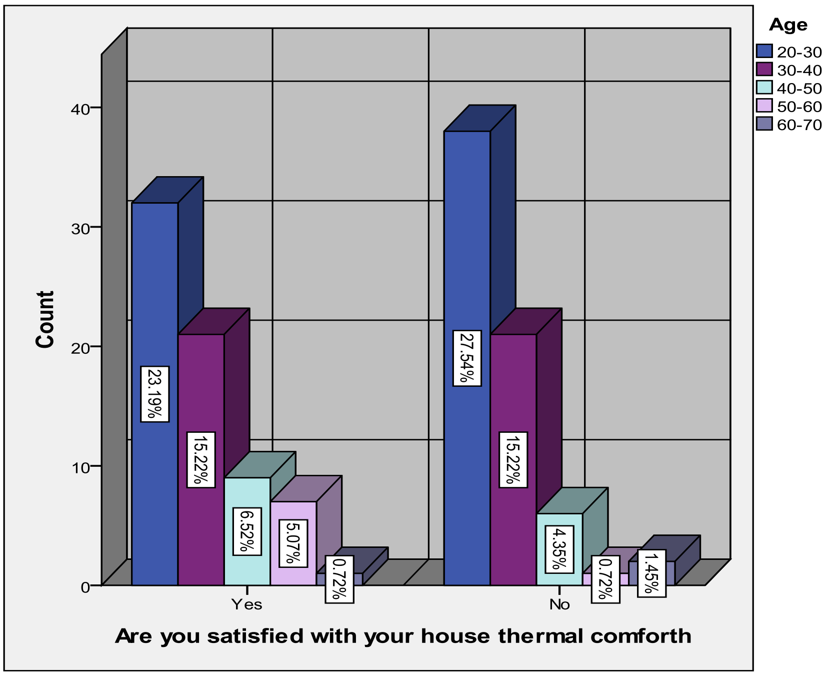

Figure 5.2 The relation between age and satisfaction with the thermal comfort of the house.

The other interesting thing about whether respondents were satisfied or unsatisfied with how cool their home is, less than 8% open the windows to cool their home, as Figure 6.3 shows.

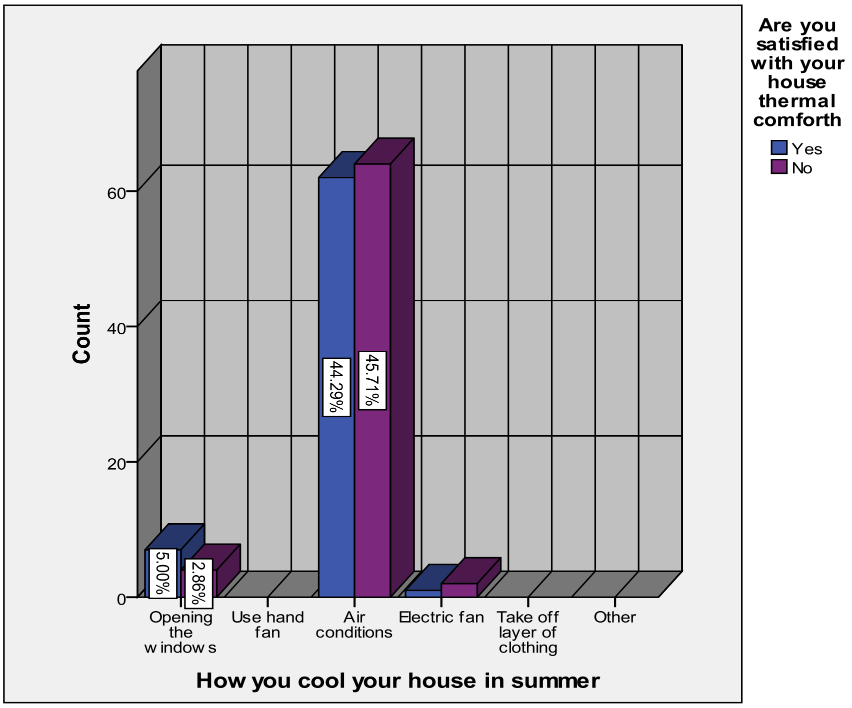

Figure 5.3 The relation between satisfaction with the house thermal comfort and how you cool your house in summer.

Figure 6.4 clearly shows that 90% of the people cool their homes by using air conditioning, which is cause for concern because of the high energy use involved.

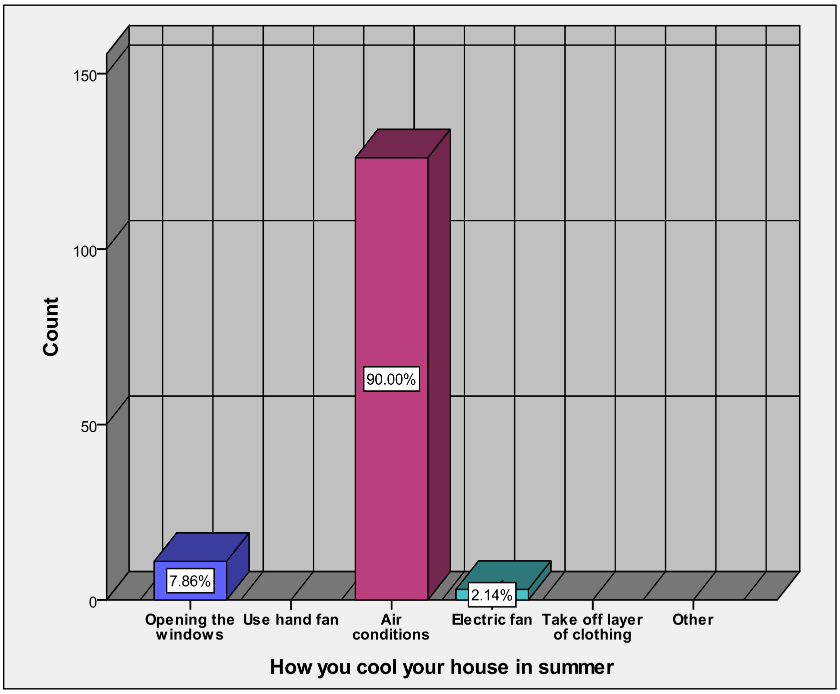

Figure 5.4 How you cool your house in summer?

Figure 6.5 shows the percentages of respondents feeling the temperature in summer; surprisingly, 10% indicate that they feel cool and 21.7% feel slightly cool' on the other hand almost 27% feel slightly warm and less than 10% feel warm.

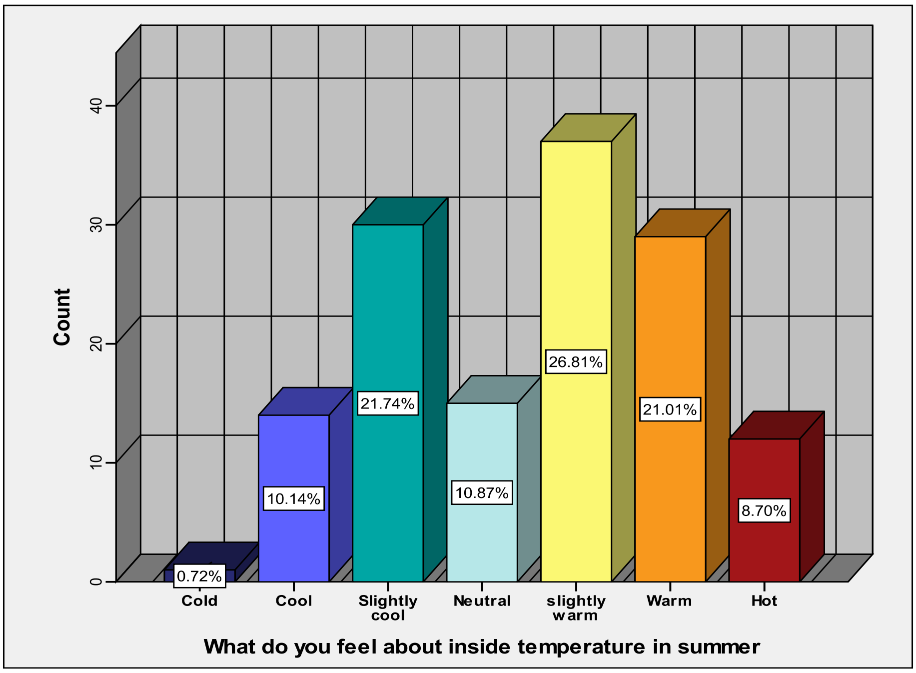

Figure 5.5 The percentage for how respondents feel the temperature in summer.

The responses regarding how respondents feel the temperature in winter is more expected, with the majority feeling cold (43%,) while around 30% feel cool and less than 17% feel slightly cool as shown in Figure 6.6.

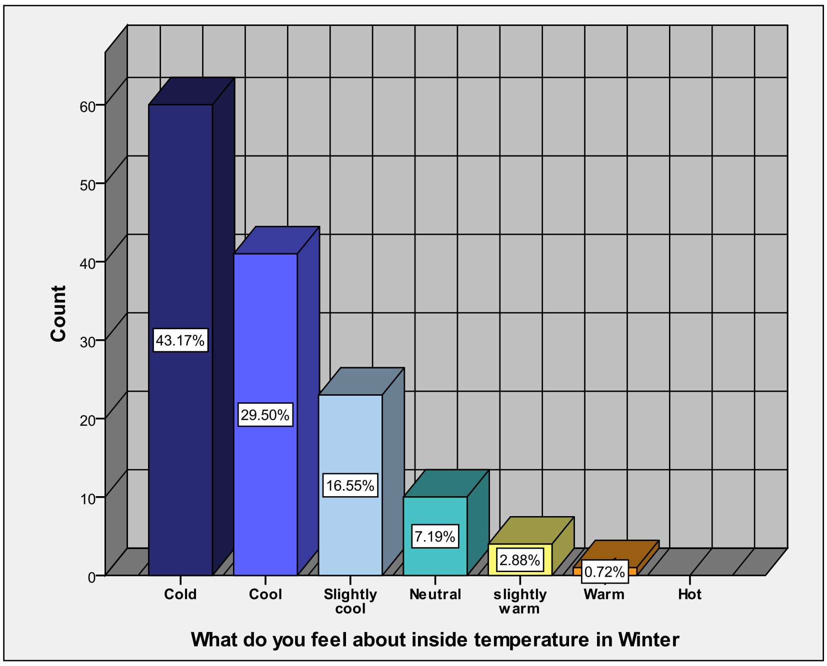

Figure 5.6 The percentage for how respondents feel the temperature in winter.

Figure 6.7 shows the relation between how respondents cool their house in summer and what they feel about the inside temperature in winter. It is clear that those who use the air conditioning to cool their homes feel colder than the others.

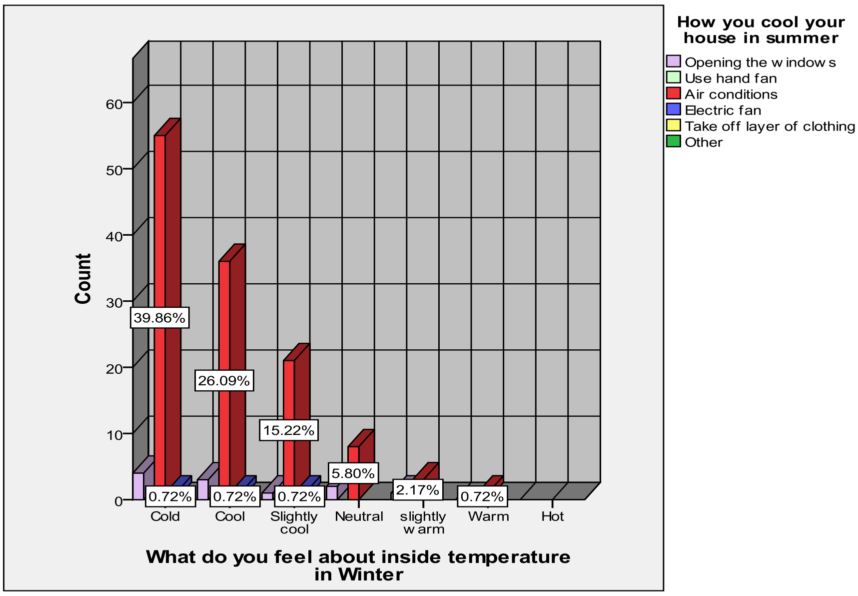

Figure 5.7 The relation between method of cooling the home in summer and feeling the temperature in winter.

The relation between how respondents cool the house in summer and how they heat the house in winter is most important as it indicates their total energy consumption. Figure 6.8 shows that 63% of the people who use electric heating in winter also use air conditioning to cool their houses in summer, while less than 14% who use air condition for bout cooling in summer and heating in winter.

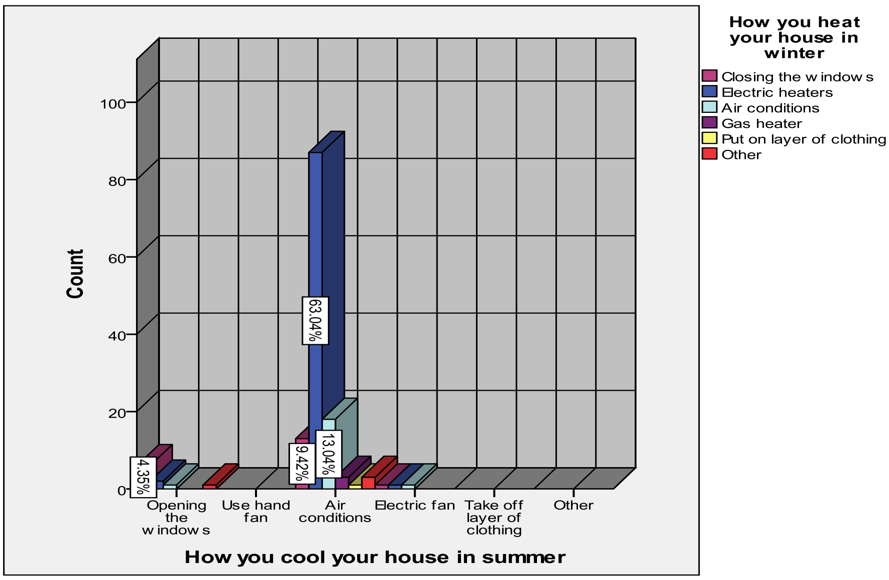

Figure 5.8 The relation between methods of heating in winter and cooling in summer.

5.2.3 Building construction

Material is very important in the building construction; Figure 6.9 shows that around 80% of those who are either how satisfied or not satisfied with their building are living in a building built with concrete bricks, only a small percentage of buildings were built with other materials.

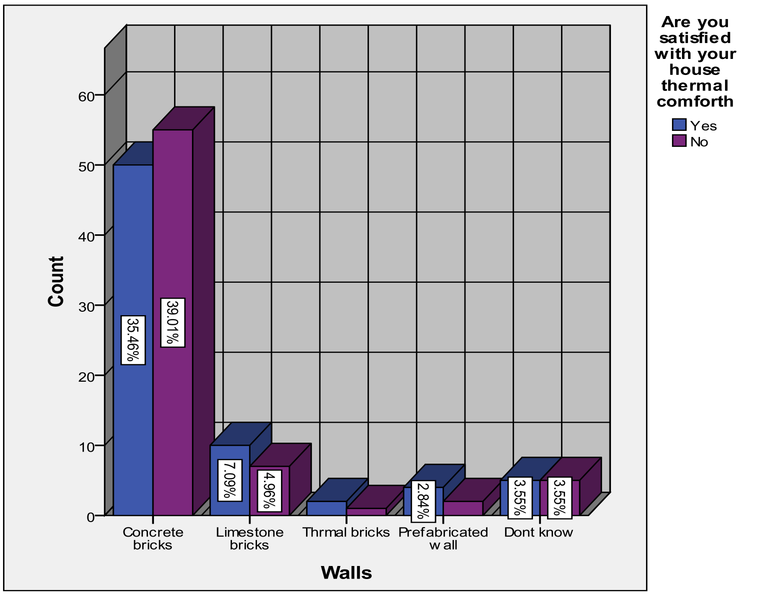

Figure 5.9 The relation between satisfaction with the house thermal comfort and wall material.

Insulation is one of the essential additions to the building that can save energy. Figure 6.10 shows the relation of satisfaction and finishing material used: 75% of the buildings are finished by painting, and only around 12% have added insulation in their buildings.

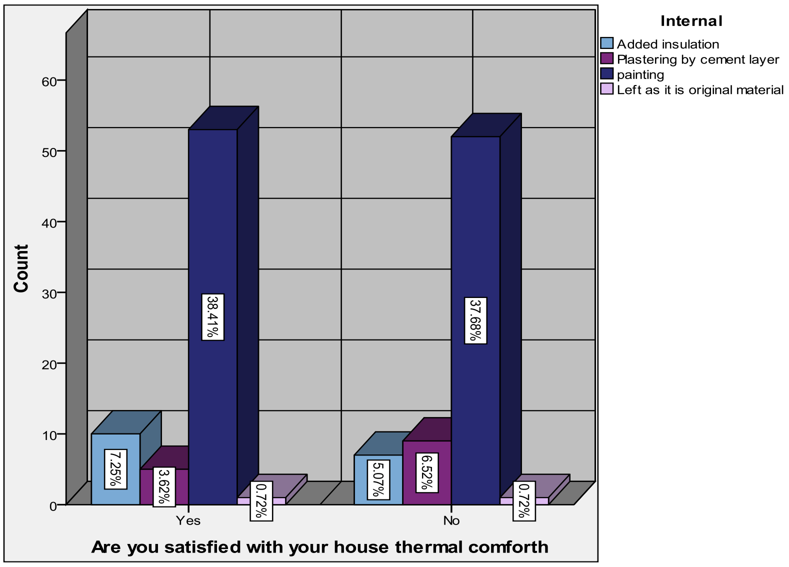

Figure 5.10 The relation between satisfactions and the wall finishing material used.

Figure 6.11 shows the building areas of the houses of participants in the questionnaire. More than 51% of their houses were more than 200m^2 and only 19% were between 50-100m^2.

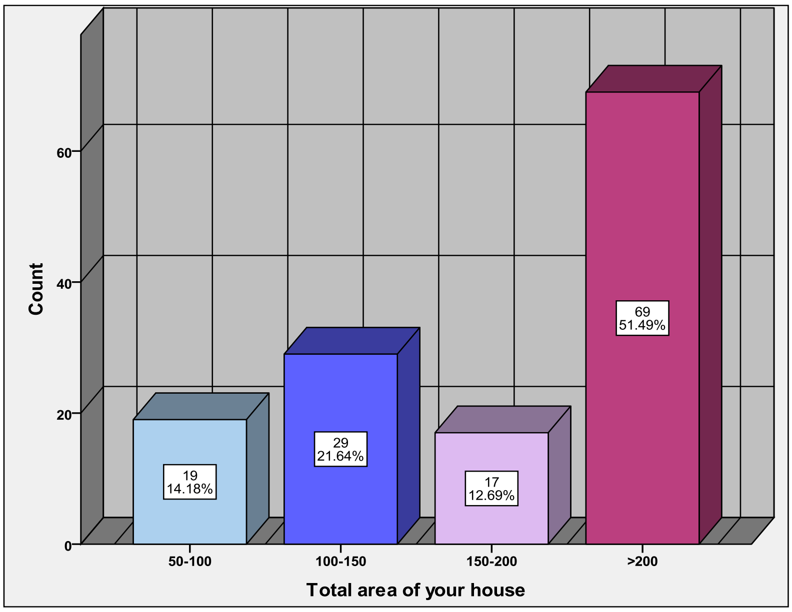

Figure 5.11 Total area of the houses.

5.2.4 Energy consumption

The amount spent on electricity bills is one of the ways to know how much the level of participants' energy consumption. Figure 6.12 shows that 47% pay less than 50 Libyan pounds per month and 30% pay between 50-100 pound per month and less than 10% pay between 150 to 250 per month. This is fully applies to what we said in the previous chapter, there are large areas which need more energy consumption but paying less.

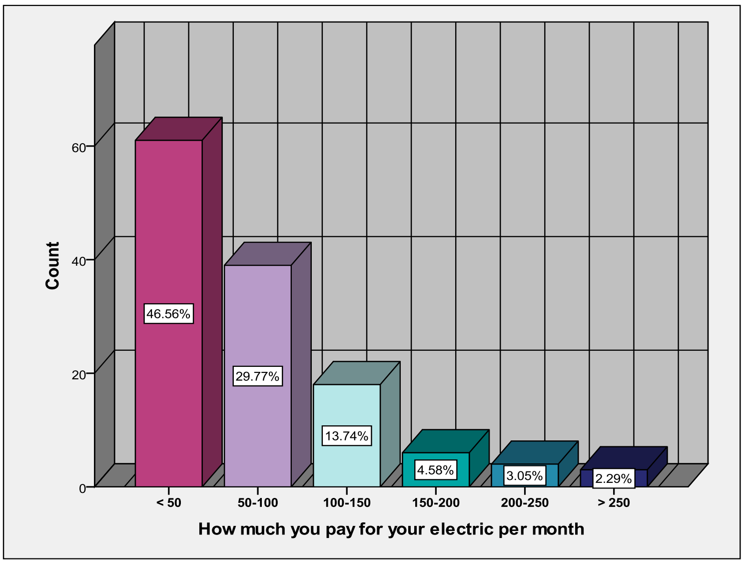

Figure 5.12 The electricity payment per month

Important point that come out of the use of air conditions is almost universal, residents are spending large amount in air conditioning.

The conditions are not always comfortable; it shows that air conditioner systems are well matched to the loads.

6 Chapter 6 IES Modelling

6.1 Introduction

This chapter identifies and discusses the software that has been used in this thesis, and clarifies the simulation results. Furthermore, it also displays the results from simulating intervention to the building to reduce electricity consumption. The analysis indicated that the best design and evaluation tool to be used is Integrated Environmental Solutions (IES-VE). Results were validated by comparison with field data taken from the case study.

6.2 Integrated Environmental Solutions (IES-VE) software

Virtual Environment by Integrated Environmental Solutions (IES-VE) is a modern example of dynamic building energy simulation software. IES-VE consists of a suite of integrated analysis tools, which can be used to investigate the performance of a building either retrospectively or during the design stages of a construction project (Figure 6.2).

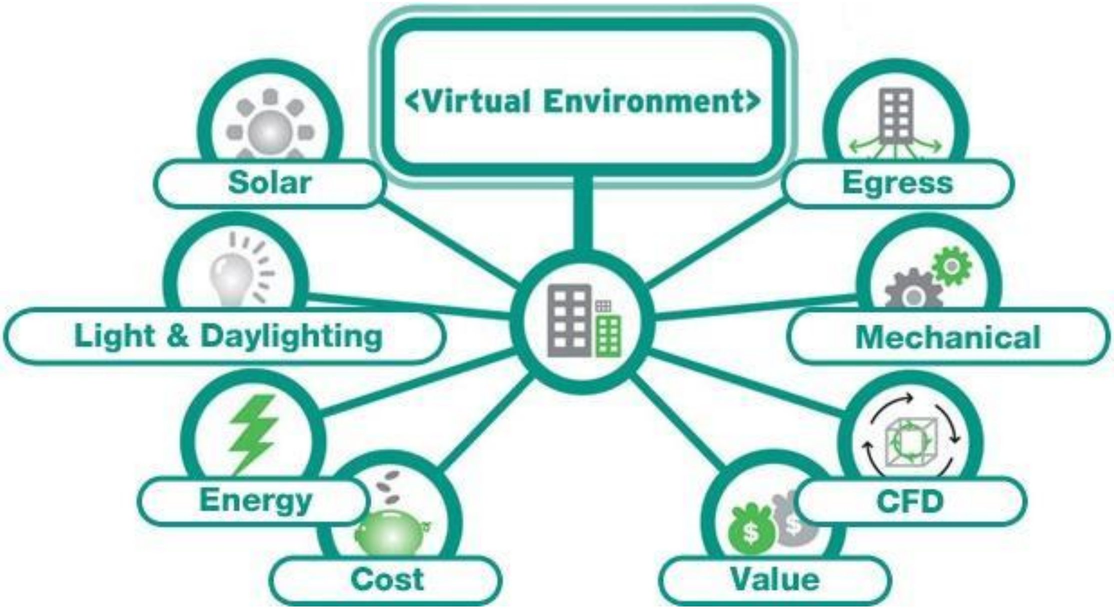

Figure 6.1 How the IES program works

IES enables the specific understanding of the site to automatically outline suitable bioclimatic architecture strategies for the project; such pre-design sustainability direction is invaluable.

Because it is a renovation project, IESVE allows identification of the best passive solutions, comparing low-carbon technologies, and drawing conclusions on energy use, CO_2 emissions, occupant comfort, light levels, and much more.
IESVE for Engineers allows easily visualising and communication of results at a highly detailed level.

A model of the building was constructed with VE using the “ModelIT” module, which was then analysed in a variety of different ways. The most commonly used is the "Apache" thermal analysis module, which provides dynamic analysis of energy consumption and indoor thermal conditions; the steps that were taken in this work are as follows.

6.3 Model

The drawing of the building data was created from scratch, at this stage, carefully and cautiously. Building details and the materials used in its construction were inputted into the IES software and incorporated in the program, including dimensions of windows and openings, as shown in Figure 6.3 and Figure 6.4.

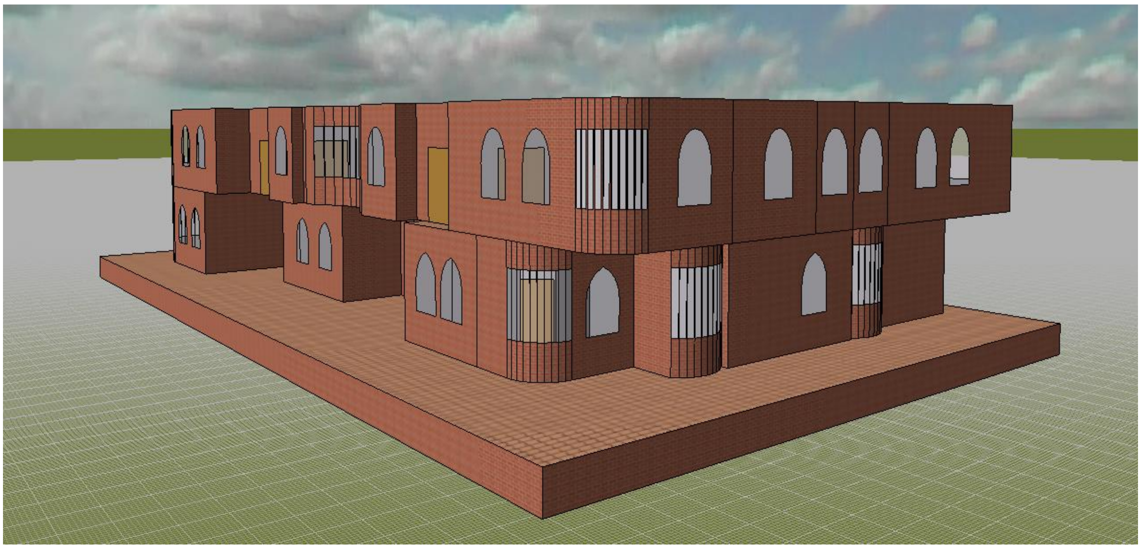

Figure 6.2 South and east elevation of the building after modelling it with IES.

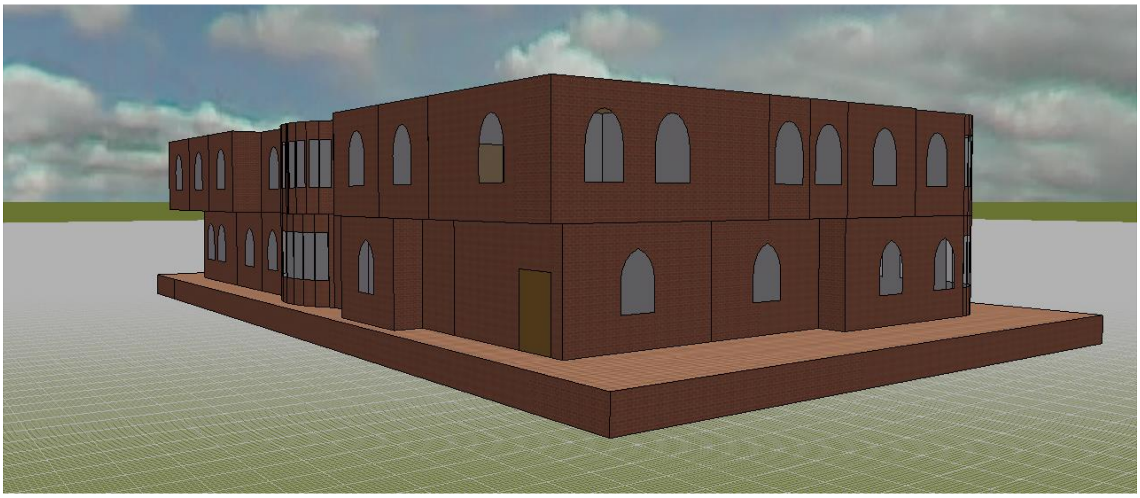

Figure 6.3 North and west elevation of the building after modelling it with IES.

6.4 Validating the data

The simulation was validated via comparison between the field measurements and the simulation results for the hot period. The calibration model showed that the difference between them was less than 1°C, as shown in Figure 6.1, which confirms that the simulation follows the same trends as the measured results and is therefore reliable for the hot climate of Tripoli.

The model was run using the same weather data as was found from the majoring, there was good agreement between the majored and the model data for internal temperature and it shows an example of the validation of the trends data.

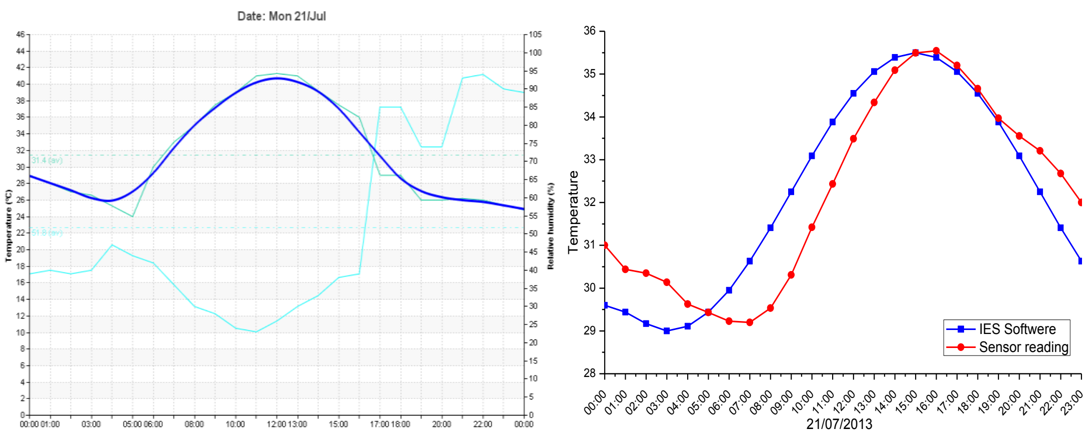

Figure 6.4 Data validation between the field measurements and the simulation results for the hot period.

6.5 Sun Cast

This calculates the position of the sun in the sky, tracks solar penetration throughout the building interior and calculates shadows. This was one of the more difficult steps because this software works with an average data; this was realised when trying to validate the data. However, it was resolved after discussion with the IES Company and by obtaining the actual temperatures for Tripoli-Libya for that year (Figure 6.5).

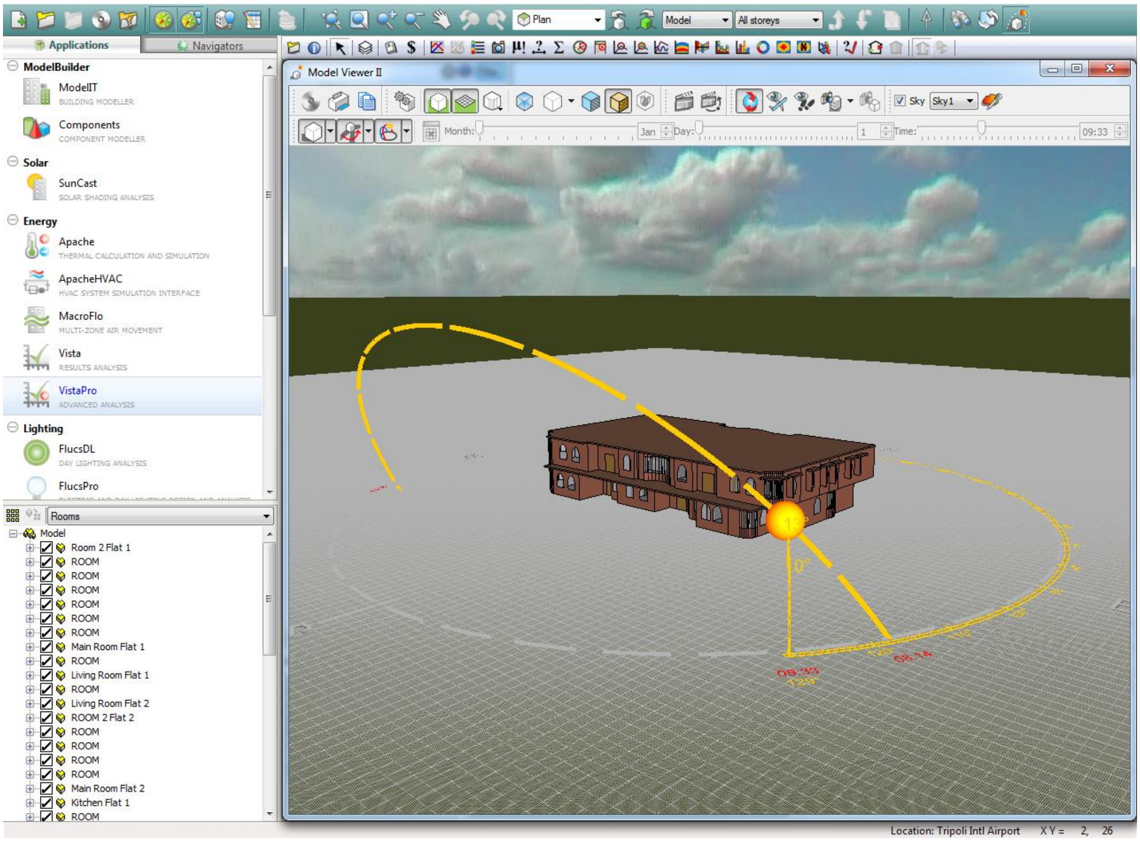

Figure 6.5 The building showing the sun cast calculation.

6.6 Apache Simulation

The central simulation process enables the user to assess every aspect of thermal performance as well as share results and input across a wide variety of other VE engineering modules. The building has been modelled by IES software as far as possible exactly as it is, with no major changes, except those inevitably required by the conditions of modelling.

Once the base model had been simulated and validated, modifications to the building were simulated as follows;

1. Shading device added on both sides east and west.
2. Adding external and internal solar film glazing with low transmission.

3. Painting the roof with white lower emissivity paint.
4. Adding insulation to the roof slab.

Figure 6.6 and Figure 6.7 show the building after adding the shading device with 70cm width and 10cm thickness, horizontally and vertically.

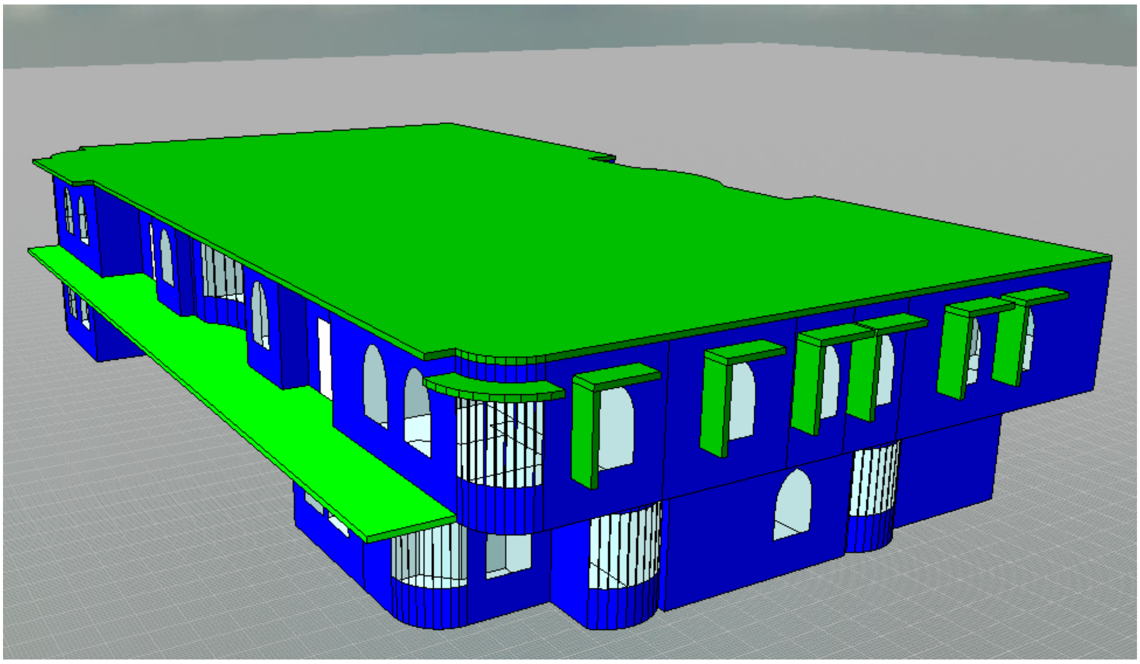

Figure 6.6 The south and east elevations of the building after adding shading.

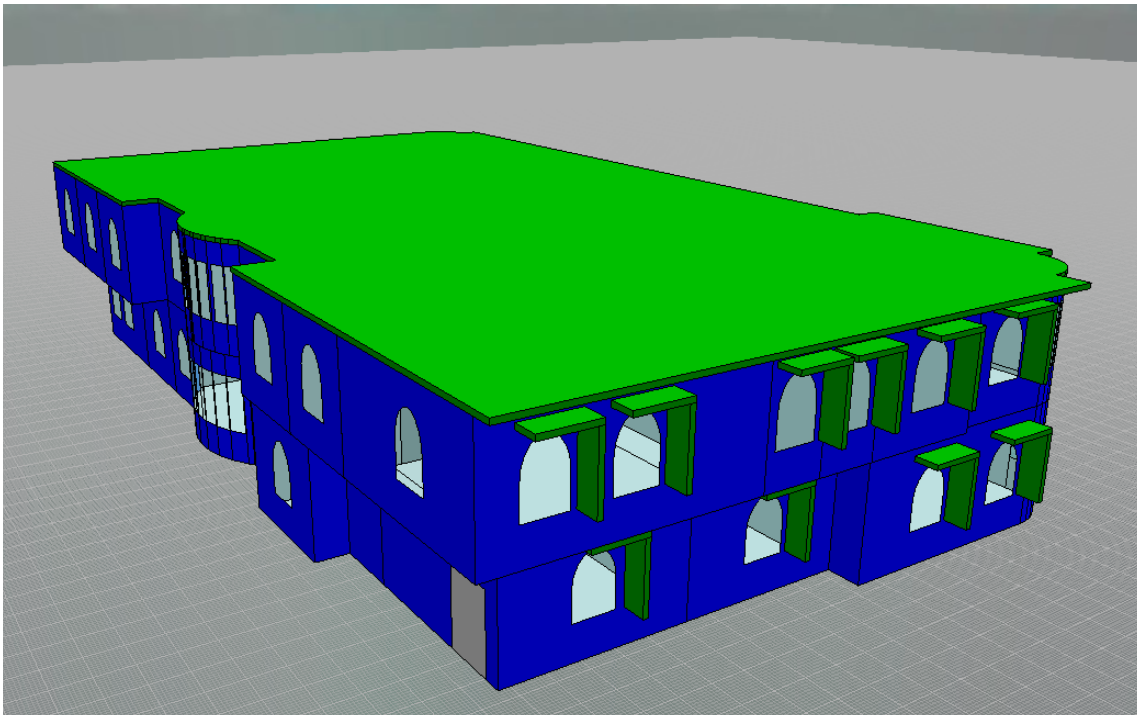

Figure 6.7 The north and west elevations of the building after adding shading.

6.7 Simulation results

6.7.1 Solar gain result:

Figure 6.8 and Figure 6.9 show the east, south, and roof simulation results for the outer surface solar gain in kWh/m^2. The gain for the east façade is on average 3.81kWh/m^2, while that for the ground floor on the south façade is less than the first floor, with 1.25kWh/m^2 compared with gain for the first floor, which is 2.28kWh/m^2. The roof is the biggest absorber in the building with above 7.61kWh/m^2.

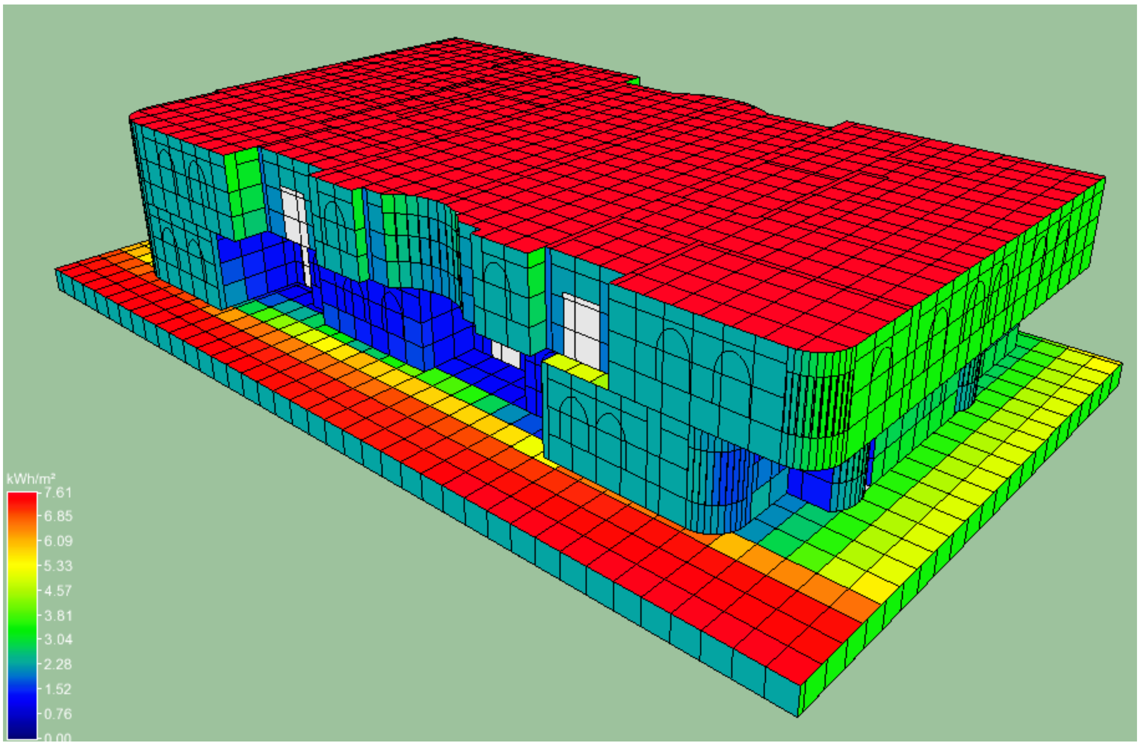

Figure 6.8 South, east, and roof solar gain simulation result.

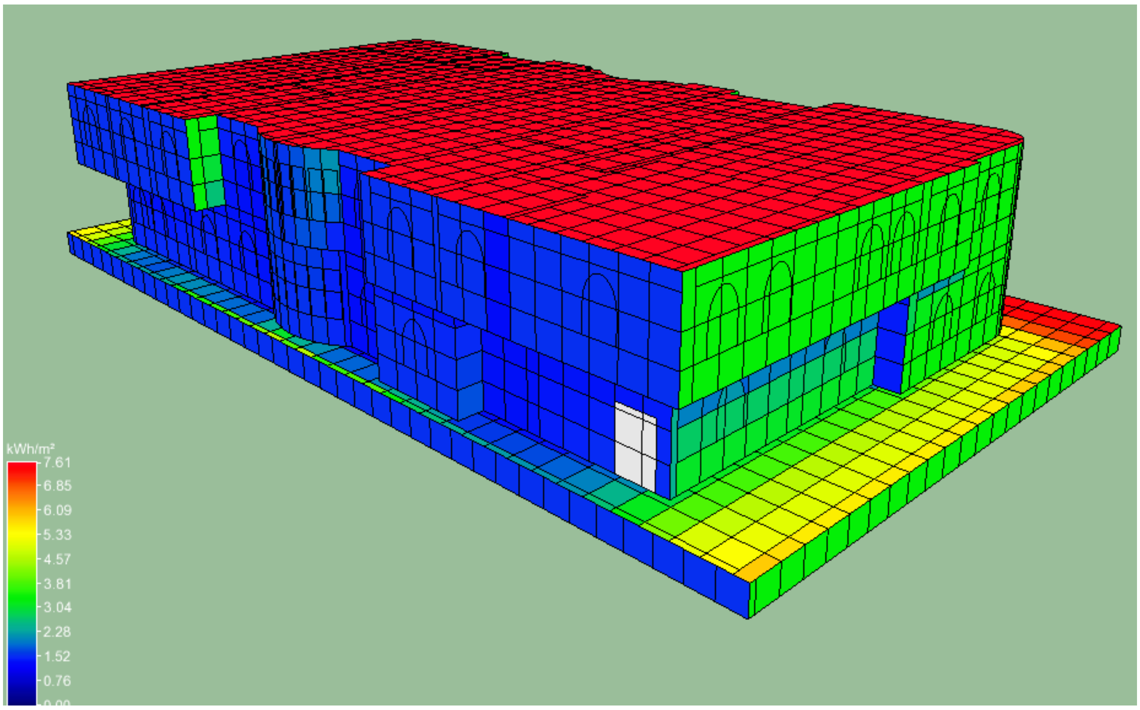

Figure 6.9 North, west, and roof solar gain simulation result.

The north façade has the lowest heat absorption of all the elevations, with less than 0.76kWh/m^2, and the west façade has almost the same absorption as the east façade with 3.81kWh/m^2.

After simulating the building solar gain for the whole year and comparing it with the values after the changes had been added to the building Figure 6.10 shows that the building solar gain in the summer time reached over 4.5Mwh. Table 6.1 shows the figures for each addition, before and after it was added to the building. As it shows that it absorbs 51.4697 Mw/h solar gains in total, this is presumed to be the 100% value. The results show that 18.5% of gains can be cut by just adding the shading devices on east and west side, while the most impressive result is by adding external solar film on the glazing, which can cut 62% from the solar gain. However, painting the roof with white paint and adding slab absorber to it did not change the result, while adding internal solar film on the glazing can cut an extra 3% to be in total a reduction of 65% in solar gain.

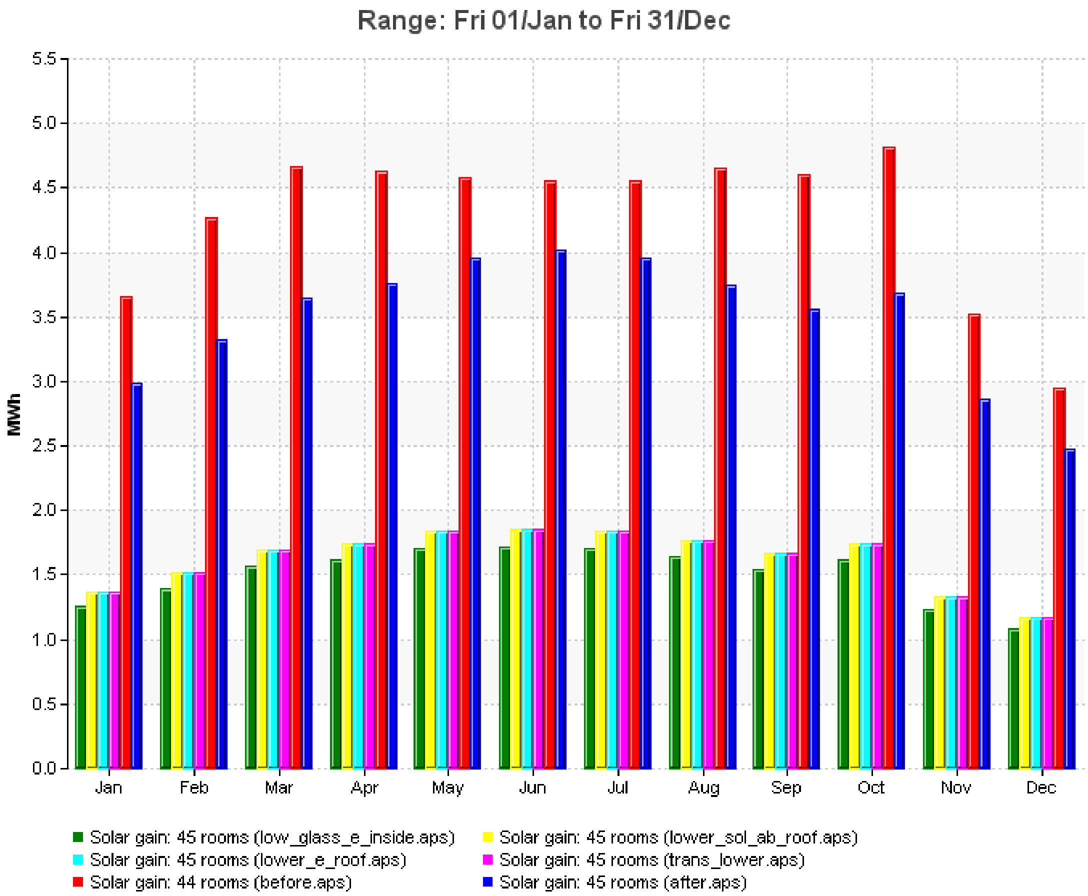

Figure 6.10 Simulation results for the building solar gain.

Table 6.1 Simulation results for the solar gain figures for each additional to the building

Solar Gain (MWh)						
Date	**Before shading devices**	**After shading**	**Glazing outside lower transmission (solar Film)**	**Lower roof emissivity (paint white)**	**Lower roof slab absorption**	**Glazing inside lower transmission (solar film)**
Jan 01-31	**3.6635**	**2.9811**	**1.3679**	**1.3679**	**1.3679**	**1.2625**
Feb 01-28	**4.2717**	**3.3177**	**1.5138**	**1.5138**	**1.5138**	**1.3960**
Mar 01-31	**4.6725**	**3.6413**	**1.6920**	**1.6920**	**1.6920**	**1.5662**
Apr 01-30	**4.6347**	**3.7567**	**1.7473**	**1.7473**	**1.7473**	**1.6167**
May 01-31	**4.5811**	**3.9543**	**1.8370**	**1.8370**	**1.8370**	**1.7001**
Jun 01-30	**4.5549**	**4.0155**	**1.8561**	**1.8561**	**1.8561**	**1.7174**
Jul 01-31	**4.5493**	**3.9519**	**1.8455**	**1.8455**	**1.8455**	**1.7092**
Aug 01-31	**4.6540**	**3.7503**	**1.7717**	**1.7717**	**1.7717**	**1.6424**
Sep 01-30	**4.6060**	**3.5556**	**1.6666**	**1.6666**	**1.6666**	**1.5436**
Oct 01-31	**4.8113**	**3.6846**	**1.7467**	**1.7467**	**1.7467**	**1.6213**
Nov 01-30	**3.5165**	**2.8613**	**1.3301**	**1.3301**	**1.3301**	**1.2295**
Dec 01-31	**2.9544**	**2.4766**	**1.1675**	**1.1675**	**1.1675**	**1.0814**
Total	**51.4697**	**41.9468**	**19.5420**	**19.5420**	**19.5420**	**18.0863**
%	**100%**	**-18.5%**	**-62.00%**	**-62.00%**	**-62.00%**	**-64.86%**

To make it more clear, Figure 6.11 illustrates the significant impact of the various measures on cutting down the solar gain.

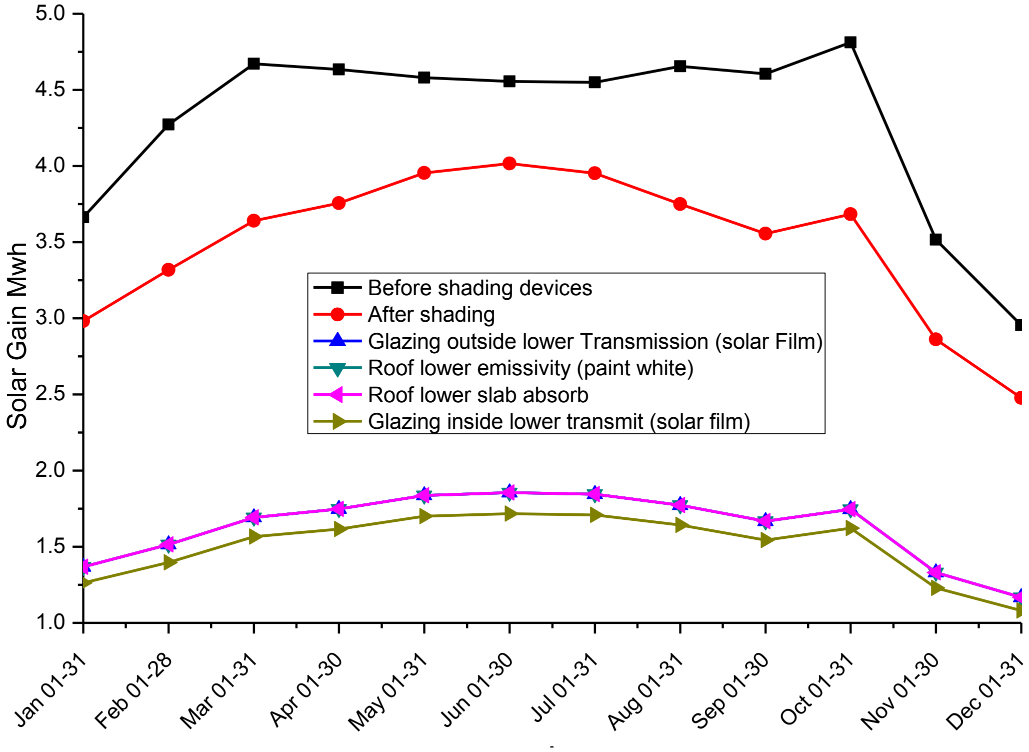

Figure 6.11 The building solar gain by each month.

To focus on the two hot months, Figure 6.12 shows the solar gain in July and August, and it is clear that before adding shading devices in both months it is above 4.5Mwh; after adding shading devices it is cut down by more than ½ Mwh for July and more than one Mwh for August, and more than 2.5Mwh by adding low transmission solar film and roof heat absorber.

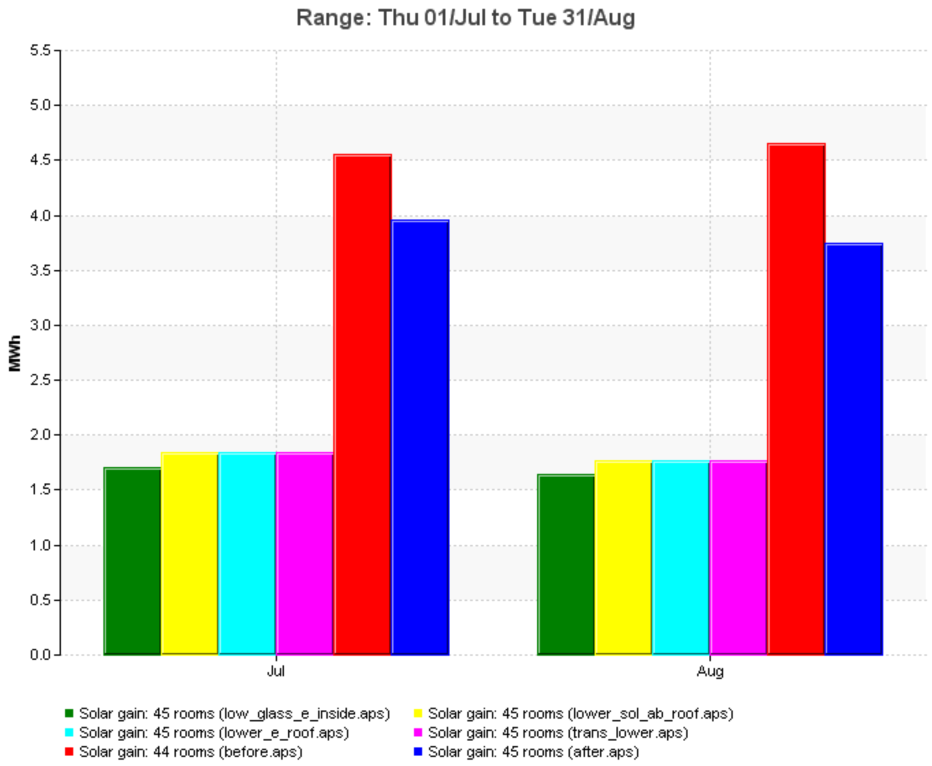

Figure 6.12 Solar gain in July and August.

Table 6.2 shows the solar gain simulation results for July and August, which show that 10.8% can be cut by just adding a shading device, while 60.7% can be cut by adding solar film outside the glazing, and an extra 3% for adding solar film inside the glazing.

Table 6.2 Solar gain simulation results for July and August

Solar gain (Mwh) for July and August						
Date	Before shading devices	After shading	Glazing: outside lower transmission (solar film)	Roof: lower emissivity (paint white)	Roof slab: lower absorption	Glazing: inside lower transmission (solar film)
Jul 01-31	4.5493	3.9519	1.8455	1.8455	1.8455	1.7092
Aug 01-31	4.6540	3.7503	1.7717	1.7717	1.7717	1.6424
Total	9.2033	7.7022	3.6172	3.6172	3.6172	3.3515
-%	100%	10.87%	60.7%	60.7%	60.7%	63.58%

6.7.2 Chiller loads

One of the largest energy users is the air-conditioning. Figure 6.13 shows how the changes can affect the chiller loads, which will lead to savings on energy consumption of varying degrees, according to the modifications made to the building.

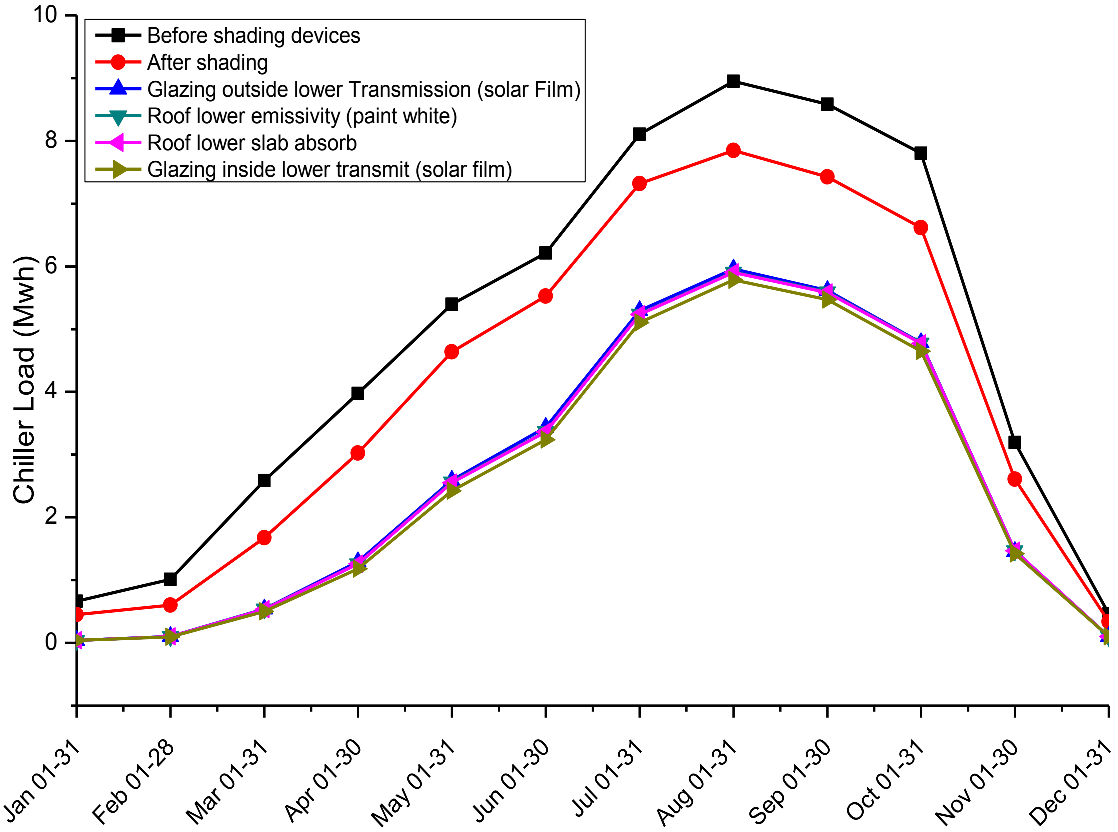

Figure 6.13 Chiller loads by month in Mwh.

Table 6.3 shows the total chiller load for each month during the year, indicating that the building uses 56.94Mw/h its current form, while if shading devices are added, it can cut 15.8% of the total chiller load, and for the best savings, the solution is to add external solar film on the glazing, which can save 45.2% of the energy. However, adding lower emissivity paint and heat absorbent insulation to the roof will add no more than 1% extra saving to the load, 2% more can be saved by adding internal solar film on the glazing, but this is probably not worth it for the impact on natural lighting to the building.

Table 6.3 Chiller load figures for each addition to the building.

Chiller Load (Mwh)						
Date	**Before shading devices**	**After shading**	**Glazing: external lower Transmission (solar Film)**	**Roof lower emissivity (paint white)**	**Heat absorbent insulation**	**Glazing internal lower transmission (solar film)**
Jan 01-31	**0.6647**	**0.4506**	**0.0379**	**0.0379**	**0.0379**	**0.0379**
Feb 01-28	**1.0130**	**0.6003**	**0.1039**	**0.1039**	**0.1039**	**0.0939**
Mar 01-31	**2.5839**	**1.6763**	**0.5394**	**0.5423**	**0.5359**	**0.5004**
Apr 01-30	**3.9747**	**3.0220**	**1.2925**	**1.2620**	**1.2608**	**1.1799**
May 01-31	**5.3953**	**4.6359**	**2.5902**	**2.5644**	**2.5526**	**2.4252**
Jun 01-30	**6.2117**	**5.5248**	**3.4344**	**3.3687**	**3.3590**	**3.2363**
Jul 01-31	**8.1078**	**7.3182**	**5.2971**	**5.2414**	**5.2319**	**5.1029**
Aug 01-31	**8.9501**	**7.8493**	**5.9582**	**5.9058**	**5.9002**	**5.7843**
Sep 01-30	**8.5826**	**7.4236**	**5.6161**	**5.5920**	**5.5812**	**5.4678**
Oct 01-31	**7.8018**	**6.6190**	**4.7862**	**4.7794**	**4.7714**	**4.6475**
Nov 01-30	**3.1922**	**2.6099**	**1.4557**	**1.4692**	**1.4666**	**1.4229**
Dec 01-31	**0.4602**	**0.3398**	**0.1044**	**0.1044**	**0.1044**	**0.1004**
Total	**56.9381**	**48.0697**	**31.2159**	**30.9714**	**30.9058**	**29.9993**
%	**100%**	**-15.6%%**	**-45.2%**	**-45.6%**	**-45.7%**	**-47.3%**

For July and August, Figure 6.14 shows that shading devices can reduce the chiller load by up to 1 Mwh in July and up to 1.5Mwh in August, and furthermore, adding outside lower transmission (solar film) to glazing can reduce the load by up to 3%.

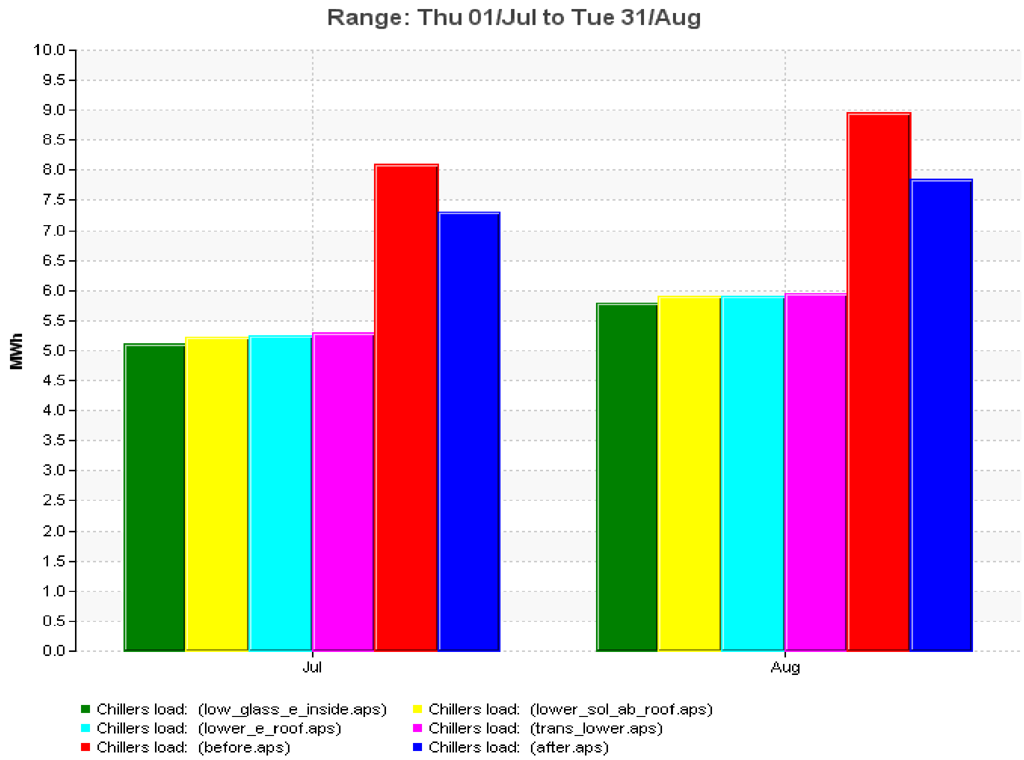

Figure 6.14 Shows chiller loads in July and August.

Table 6.4 shows the chiller load simulation results for July and August; the results show that up to 11% can be cut by adding shading device, while up to 34% is cut by then adding solar film outside the glazing. Application of lower emissivity roof paint can bring the cut to 34.65% from the total chiller load, whereas lower heat absorbent roof insulation did not add any change, while finally adding solar film inside the glazing can achieve a total of up to 36.18% reduction in the total chiller load.

Table 6.6.4 Chiller load simulation results for July and August.

Chillers load (MWh) for July and August						
Date	Before shading devices	After shading	Glazing outside lower Transmission (solar Film)	Roof lower emissivity (paint white)	Roof lower slab absorb	Glazing inside lower transmit (solar film)
Jul 01-31	8.1078	7.3182	5.2971	5.2414	5.2319	5.1029
Aug 01-31	8.9501	7.8493	5.9582	5.9058	5.9002	5.7843
Total	17.0579	15.1675	11.2552	11.1472	11.1321	10.8871
%	100%	-11.08%	-34.02%	-34.65%	-34.74%	-36.18%

6.7.3 CO2 produced by the building

From the global viewpoint the most important aspect is how much we can make this building save in producing CO_2. Figure 6.15 clearly indicates how much the changes can save CO_2 by Kg each month for the whole year. It is clear that summer time is the peak CO_2 producer; that is because the building uses air conditioning more at that time than in the rest of the year. The higher the temperature increase, the more CO2 is produced, in appositive relationship.

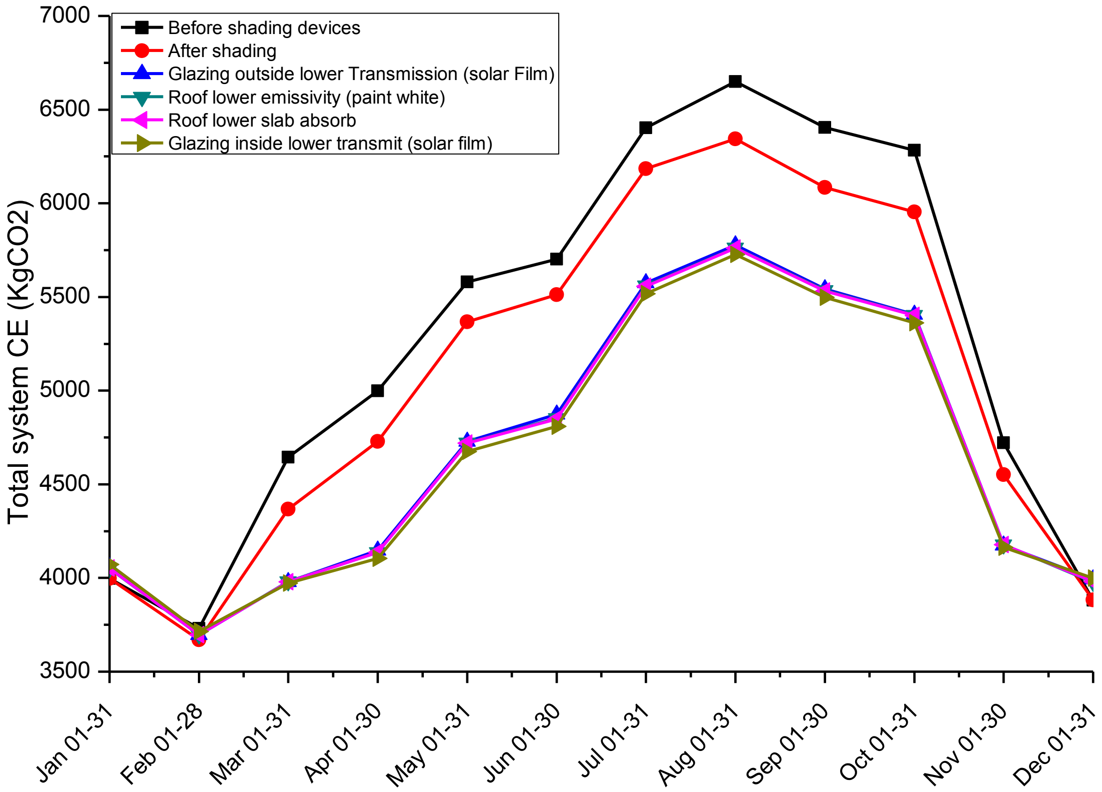

Figure 6.15 The total CO2 produced by the building.

Table 6.5 shows the total amount of CO2 in Kg for each month during the year. The results show that the building initially produced 62995Kg CO2 yearly. After adding shading devices, it became 60644Kg, 3.8% less and fell to 55951Kg, 11.2% less than the original production, by also adding external solar film. However, the remaining results show that adding lower emissivity pain and lower absorbance insulation to the roof followed by solar film inside the glazing did not change the amount of CO_2 more than 0.5%.

Table 6.5 CO_2 production figures for each addition to the building.

Total system CE (kgCO2)						
Date	**Before shading devices**	**After shading**	**Glazing: external lower Transmission (solar Film)**	**Roof lower emissivity (paint white)**	**Heat absorbent insulation**	**Glazing internal lower transmission (solar film)**
Jan 01-31	**3997**	**3998**	**4058**	**4050**	**4052**	**4072**
Feb 01-28	**3731**	**3670**	**3697**	**3696**	**3697**	**3714**
Mar 01-31	**4645**	**4367**	**3980**	**3981**	**3979**	**3972**
Apr 01-30	**4999**	**4728**	**4148**	**4136**	**4136**	**4104**
May 01-31	**5580**	**5368**	**4729**	**4722**	**4719**	**4675**
Jun 01-30	**5701**	**5512**	**4873**	**4852**	**4849**	**4810**
Jul 01-31	**6403**	**6184**	**5575**	**5561**	**5557**	**5517**
Aug 01-31	**6649**	**6344**	**5776**	**5762**	**5761**	**5726**
Sep 01-30	**6405**	**6085**	**5543**	**5536**	**5532**	**5497**
Oct 01-31	**6282**	**5954**	**5406**	**5403**	**5401**	**5361**
Nov 01-30	**4721**	**4552**	**4174**	**4178**	**4177**	**4164**
Dec 01-31	**3881**	**3882**	**3993**	**3978**	**3981**	**3999**
Total	**62995**	**60644**	**55951**	**55856**	**55842**	**55611**
%	**100%**	**-3.8%**	**-11.2%**	**-11.3%**	**-11.4%**	**-11.7%**

6.7.4 Chiller energy

Figure 6.16 shows the chiller energy consumption for the whole year, illustrating that the greatest use of energy is in summer time, especially from July to October. Energy consumption starts to increase gradually from March, to reach peak in August, and then reduces gradually until October and falls away in November. In winter time, from December to February chiller energy consumption is almost non-existent or insignificant compared to the summer months.

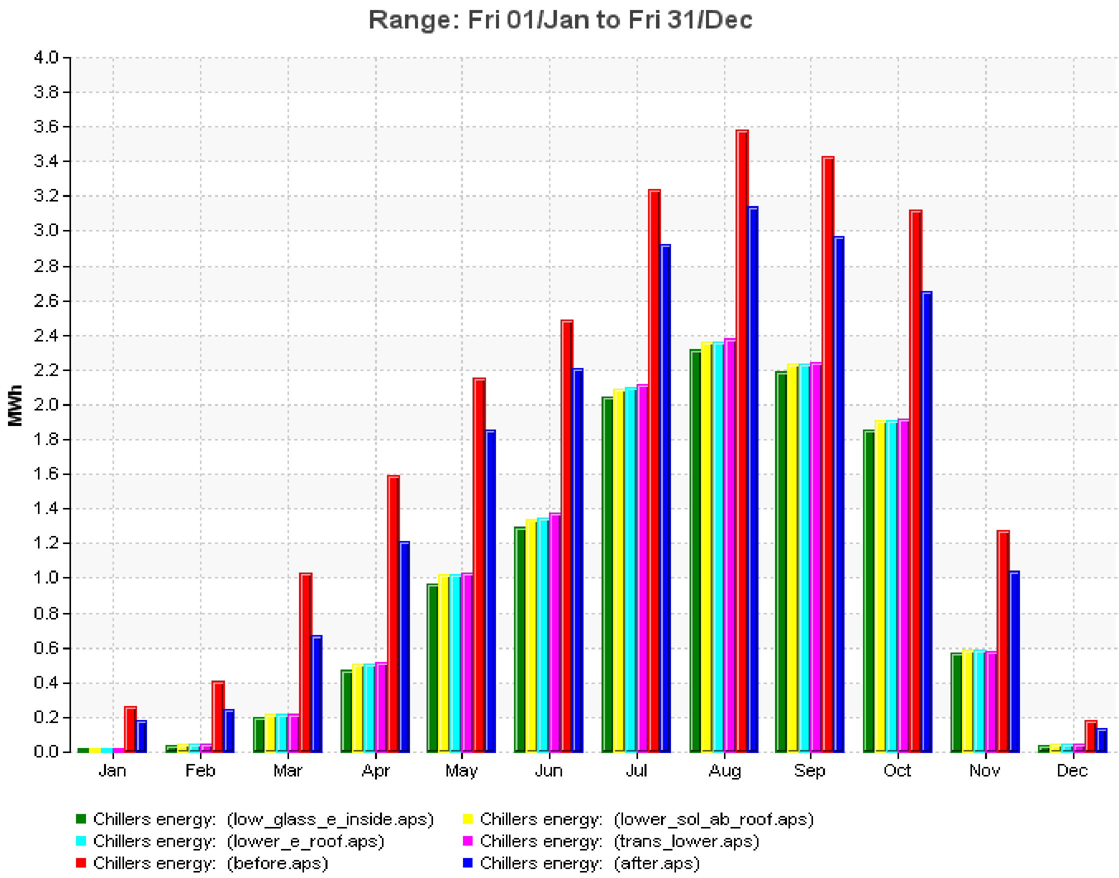

Figure 6.16 Chiller energy consumption use for the whole year.

Chiller energy consumption is one of the measures that the additions were able to reduce by approximately half of the original total. Table 7.6 shows the simulation results for the whole year. At present, the building uses 22.78MWh/year and after placing the shading devices it becomes 19.25MWh/year, representing a 15.6% reduction in consumption, while a huge reduction is achieved after placing solar film with lower transmission outside the glazing, when the total chiller energy consumption becomes only 12.49MWh/year, a reduction of 45.2%. For further reduction solar film can be placed inside the glazing and this can reduce consumption by an extra 2% to achieve 47.3% reduction in total.

Table 6.6 Chiller energy use simulation results.

Chiller Energy (MWh)						
Date	**Before shading devices**	**After shading**	**Glazing: external lower Transmission (solar Film)**	**Roof lower emissivity (paint white)**	**Heat absorbent insulation**	**Glazing internal lower transmission (solar film)**
Jan 01-31	**0.2659**	**0.1802**	**0.0152**	**0.0152**	**0.0152**	**0.0152**
Feb 01-28	**0.4052**	**0.2401**	**0.0416**	**0.0416**	**0.0416**	**0.0375**
Mar 01-31	**1.0336**	**0.6705**	**0.2158**	**0.2169**	**0.2143**	**0.2002**
Apr 01-30	**1.5899**	**1.2088**	**0.5170**	**0.5048**	**0.5043**	**0.4719**
May 01-31	**2.1581**	**1.8544**	**1.0361**	**1.0257**	**1.0210**	**0.9701**
Jun 01-30	**2.4847**	**2.2099**	**1.3738**	**1.3475**	**1.3436**	**1.2945**
Jul 01-31	**3.2431**	**2.9273**	**2.1188**	**2.0966**	**2.0928**	**2.0411**
Aug 01-31	**3.5801**	**3.1397**	**2.3833**	**2.3623**	**2.3601**	**2.3137**
Sep 01-30	**3.4330**	**2.9694**	**2.2465**	**2.2368**	**2.2325**	**2.1871**
Oct 01-31	**3.1207**	**2.6476**	**1.9145**	**1.9118**	**1.9086**	**1.8590**
Nov 01-30	**1.2769**	**1.0440**	**0.5823**	**0.5877**	**0.5866**	**0.5692**
Dec 01-31	**0.1841**	**0.1359**	**0.0418**	**0.0418**	**0.0418**	**0.0402**
Total	**22.7753**	**19.2279**	**12.4864**	**12.3886**	**12.3623**	**11.9997**
%	**100%**	**-15.6%**	**-45.2%**	**-45.6%**	**-54.8%**	**-47.3%**

6.7.5 Flat 4 study

AS flat 4 has no air conditioning, it was interesting to carry out further analysis and IES simulation in terms of temperature. Changing the properties of the windows to simulate a shading device mashrabia enabled the change of temperature to be simulated. Figure 6.16 shows the main room, living room, and kitchen temperature with normal glass specification from the 5th of July to the 16th of August. As can be seen, from the 1st to the 6th of August the temperature is stable, and the 3rd of August was chosen to carry out the simulation.

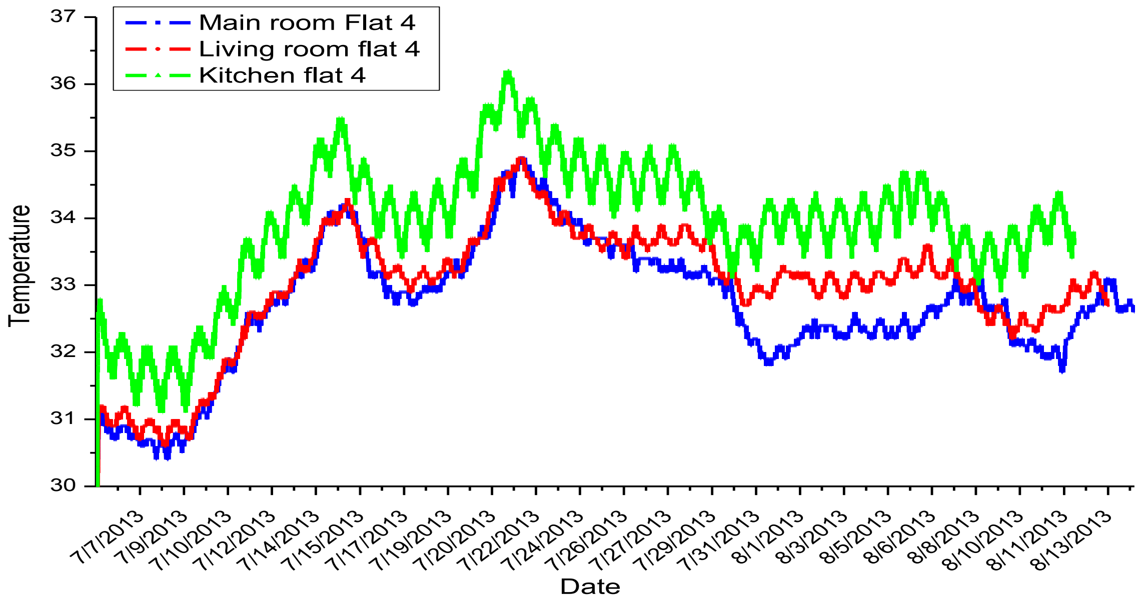

Figure 6.17 shows the main room, living room, and kitchen temperature with normal glass specification from the 5th of July to the 16th of August.

Comparing flat 4 temperature before and after changing to mashrabia, it is clear that more than 2°C has been reduced as can be seen in figure 6.18.

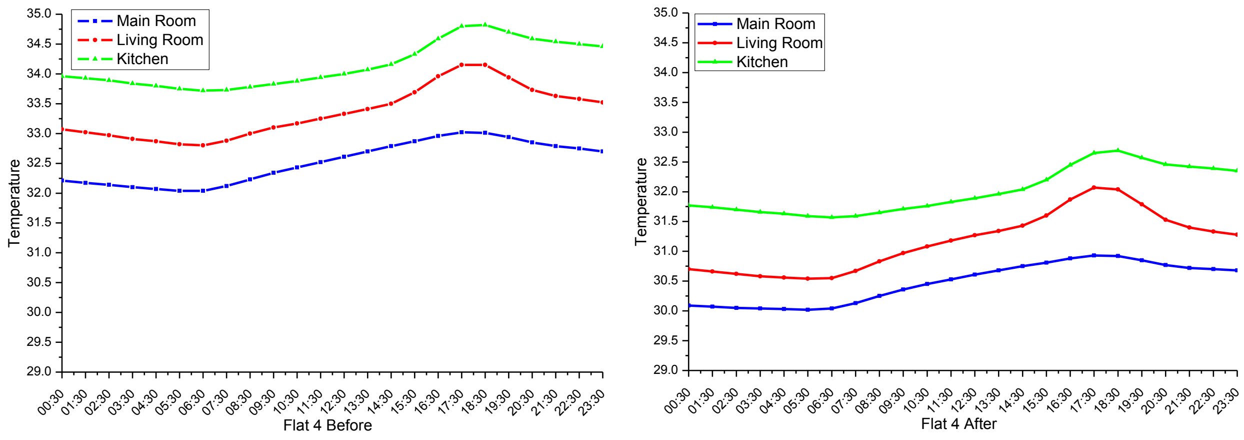

Figure 6.18 flat 4 temperatures before and after adding the mashrabia.

Table 6.7 shows the temperature for the three main elements for flat 4 before adding the mashrabia.

Table 6.7 flat 4 temperatures before adding the mashrabia.

Flat 4 before			
Air temperature (°C)			
Time	**Living Room**	**Main Room**	**Kitchen**
00:30	**32.21**	**33.07**	**33.96**
01:30	**32.17**	**33.02**	**33.93**
02:30	**32.14**	**32.97**	**33.89**
03:30	**32.10**	**32.91**	**33.84**
04:30	**32.07**	**32.87**	**33.80**
05:30	**32.04**	**32.82**	**33.75**
06:30	**32.04**	**32.80**	**33.72**
07:30	**32.12**	**32.88**	**33.73**
08:30	**32.23**	**33.00**	**33.78**
09:30	**32.34**	**33.10**	**33.83**
10:30	**32.43**	**33.17**	**33.88**
11:30	**32.52**	**33.25**	**33.94**
12:30	**32.61**	**33.33**	**34.00**
13:30	**32.70**	**33.41**	**34.07**
14:30	**32.79**	**33.50**	**34.16**
15:30	**32.87**	**33.69**	**34.33**
16:30	**32.96**	**33.96**	**34.59**
17:30	**33.02**	**34.15**	**34.80**
18:30	**33.01**	**34.15**	**34.82**
19:30	**32.94**	**33.94**	**34.70**
20:30	**32.85**	**33.73**	**34.59**
21:30	**32.79**	**33.63**	**34.54**
22:30	**32.75**	**33.58**	**34.50**
23:30	**32.70**	**33.52**	**34.46**

Table 6.8 shows the temperature for the three main elements for flat 4 after adding the mashrabia.

Table 6.8 flat 4 temperatures after adding the mashrabia.

Flat 4 after			
Air temperature (°C)			
Time	Living Room	Main Room	Kitchen
00:30	30.09	30.70	31.77
01:30	30.07	30.66	31.74
02:30	30.05	30.62	31.70
03:30	30.04	30.58	31.66
04:30	30.03	30.56	31.63
05:30	30.02	30.54	31.59
06:30	30.04	30.55	31.57
07:30	30.13	30.67	31.59
08:30	30.25	30.83	31.65
09:30	30.36	30.97	31.71
10:30	30.45	31.08	31.76
11:30	30.53	31.18	31.83
12:30	30.61	31.27	31.89
13:30	30.68	31.34	31.96
14:30	30.75	31.43	32.04
15:30	30.81	31.60	32.20
16:30	30.88	31.87	32.45
17:30	30.93	32.07	32.65
18:30	30.92	32.04	32.69
19:30	30.85	31.79	32.57
20:30	30.77	31.53	32.46
21:30	30.72	31.40	32.42
22:30	30.70	31.33	32.39
23:30	30.68	31.28	32.35

By focussing on each element separately figure 6.19 shows the main room temperature before and after adding the mashrabia to the room, it is clear that the reduction is more than 2°C. Moreover, this reduction applies to the living room and the kitchen as well as in figure 6.20 and 6.21.

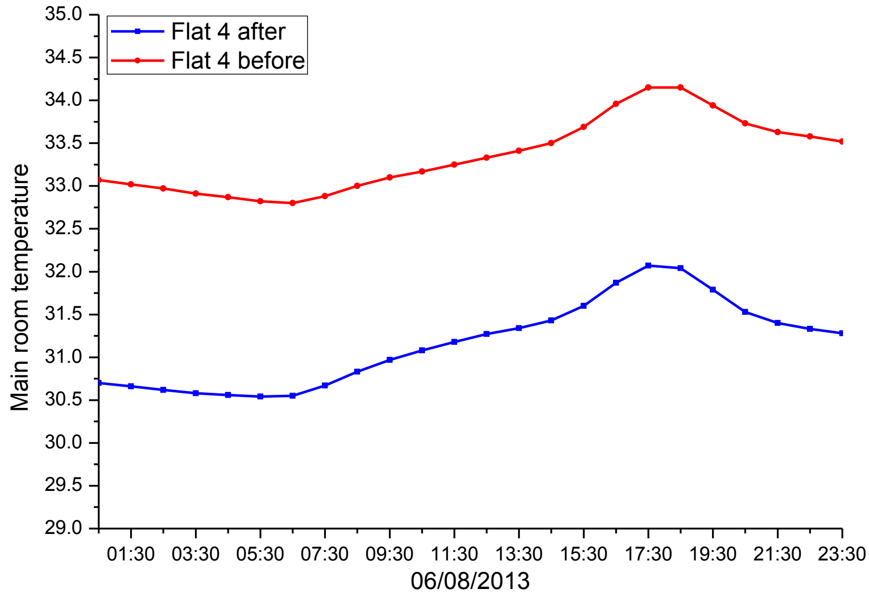

Figure 6.19 Main room temperature before and after adding the mashrabia

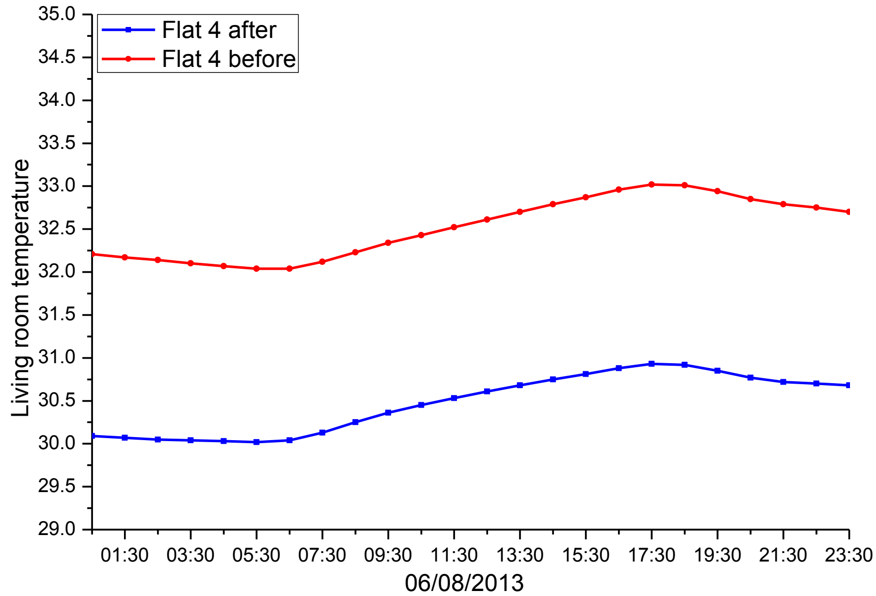

Figure 6.20 Living room temperature before and after adding the mashrabia

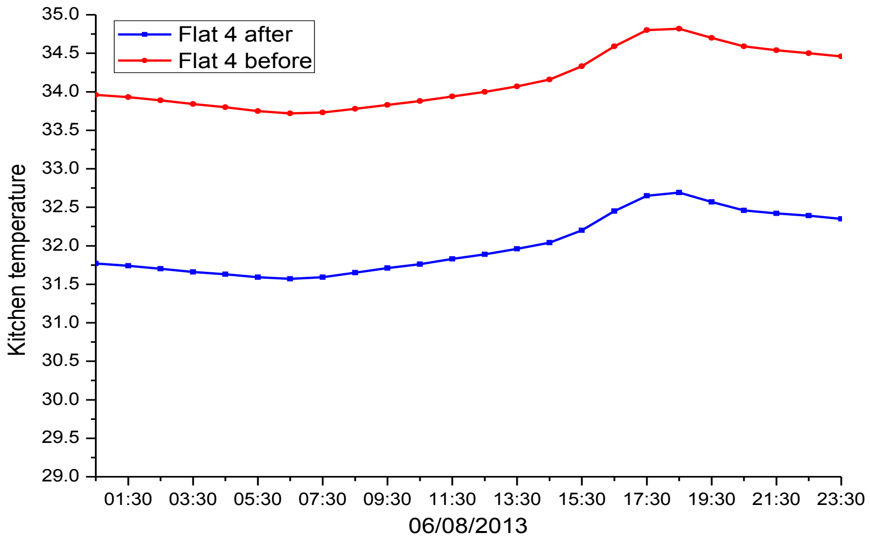

Figure 6.21 Kitchen temperature before and after adding the mashrabia

Table 6.9 shows comparing between flat 4 temperature before and after .

Table 6.9 flat 4 temperatures before and after.

Time	Air temperature (°C)					
	Living Room	Main Room	Kitchen	Living Room	Main Room	Kitchen
	Flat 4 with Mashrabia			Flat 4 before Mashrabia		
00:30	30.09	30.70	31.77	32.21	33.07	33.96
01:30	30.07	30.66	31.74	32.17	33.02	33.93
02:30	30.05	30.62	31.70	32.14	32.97	33.89
03:30	30.04	30.58	31.66	32.10	32.91	33.84
04:30	30.03	30.56	31.63	32.07	32.87	33.80
05:30	30.02	30.54	31.59	32.04	32.82	33.75
06:30	30.04	30.55	31.57	32.04	32.80	33.72
07:30	30.13	30.67	31.59	32.12	32.88	33.73
08:30	30.25	30.83	31.65	32.23	33.00	33.78
09:30	30.36	30.97	31.71	32.34	33.10	33.83
10:30	30.45	31.08	31.76	32.43	33.17	33.88
11:30	30.53	31.18	31.83	32.52	33.25	33.94
12:30	30.61	31.27	31.89	32.61	33.33	34.00
13:30	30.68	31.34	31.96	32.70	33.41	34.07
14:30	30.75	31.43	32.04	32.79	33.50	34.16
15:30	30.81	31.60	32.20	32.87	33.69	34.33
16:30	30.88	31.87	32.45	32.96	33.96	34.59
17:30	30.93	32.07	32.65	33.02	34.15	34.80
18:30	30.92	32.04	32.69	33.01	34.15	34.82
19:30	30.85	31.79	32.57	32.94	33.94	34.70
20:30	30.77	31.53	32.46	32.85	33.73	34.59
21:30	30.72	31.40	32.42	32.79	33.63	34.54
22:30	30.70	31.33	32.39	32.75	33.58	34.50
23:30	30.68	31.28	32.35	32.70	33.52	34.46

Table 6.10 shows the reduction in terms of temperature for each element as following main room by 2.19°C, living room 2.04°C, and kitchen by 2.14°C, converting this to energy it has been found elsewhere that to decrease the temperature by 1°C for each m^3 it needs approximately 11Watt under normal insulation conditions. Moreover, it has been found by adding the mashrabia for each element, the main room would need 21000W to produce this reduction if air conditioning were used, the living room would need 28625W, and the kitchen would need 13513W. Furthermore, translating this to energy costs, each W costs 0.25, by adding mashrabia to these elements it could save 16.476 Libyan dinars per day for just decreasing average by 2°C.

Table 6.10 temperature reduction and saving.

Flat 4 temperature reduction								
	°C	W	°C	W	°C	W	Total watt saving	Money saving 0.25
Time	Living room	Watt saving	Main room	Watt saving	Kitchen	Watt saving		
00:30	2.12	1242	2.37	947	2.19	577	2766	691.5
01:30	2.1	1230	2.36	943	2.19	577	2750	687.5
02:30	2.09	1224	2.35	939	2.19	577	2740	685
03:30	2.06	1207	2.33	931	2.18	574	2712	678
04:30	2.04	1195	2.31	923	2.17	571	2689	672.25
05:30	2.02	1183	2.28	911	2.16	569	2663	665.75
06:30	2	1171	2.25	899	2.15	566	2636	659
07:30	1.99	1166	2.21	883	2.14	563	2612	653
08:30	1.98	1160	2.17	867	2.13	561	2588	647
09:30	1.98	1160	2.13	851	2.12	558	2569	642.25
10:30	1.98	1160	2.09	835	2.12	556	2551	637.75
11:30	1.99	1166	2.07	827	2.11	555	2548	637
12:30	2	1171	2.06	823	2.11	555	2549	637.25
13:30	2.02	1183	2.07	827	2.11	555	2565	641.25
14:30	2.04	1195	2.07	827	2.12	558	2580	645
15:30	2.06	1207	2.09	835	2.13	561	2603	650.75
16:30	2.08	1218	2.09	835	2.14	563	2616	654
17:30	2.09	1224	2.08	831	2.15	566	2621	655.25
18:30	2.09	1224	2.11	843	2.13	561	2628	657
19:30	2.09	1224	2.15	859	2.13	561	2644	661
20:30	2.08	1218	2.2	879	2.13	561	2658	664.5
21:30	2.07	1113	2.23	891	2.12	558	2562	640.5
22:30	2.05	1201	2.25	899	2.11	555	2655	663.75
23:30	2.02	1183	2.24	895	2.11	555	2633	658.25
	2.04°C	28625W	2.19°C	21000W	2.14°C	13513W	63138 W	16.476 L.D

6.8 Conclusion

As cooling is the major energy consumer, chiller energy use has been used as the main benchmark of energy consumption. From the simulations showing changes in consumption of chiller energy as a result of various modifications together with the findings from the literature review and the investigations in the previous chapters, the following conclusions, can be drawn.

- To achieve comfortable and energy efficient buildings in Libya, controlling the amount of sunlight and heat from the sun that enters the building is the key. Location is an important factor in determining energy consumption. Different regions of the country face different weather patterns and energy related behaviour.
- Decisions taken at the early design stages have a significant impact on the energy consumption of a building. Orientation, building form, fenestration and construction materials are often decided early in the design by architects.
- The key factor affecting solar gain is ***orientation***. Proper orientation is the most important strategy. Whenever possible, the amount of window and wall area on the east and west facades should be limited. Sunlight is easier to control on the north and south sides.
- As a general rule, for any given volume of building to be heated, the smaller the exposed envelope area of this volume, the lower the heat loss. Hence, ***building form*** is an important factor influencing heat gain through the whole building, as cooling energy consumption has a significant influence on energy use.
- ***Energy efficient window design*** takes into account the window area, glass type, building orientation, and shading device to maximize day-light while minimizing solar heat gain in summer. Windows have a significant impact on energy efficiency and comfort. The three main principles of efficient window design are listed below:
- Maximize winter heat gain by orientating the windows to the south and sizing windows to suit the amount of thermal mass.
- Minimize summer heat gain by protecting windows with external shading devices, and through appropriate sizing and positioning of windows.

- ***Exterior shading***, such as horizontal overhangs and vertical fins, is a good way to decrease the amount of solar gain into a building and can also enhance the exterior design of a structure. In particular, shading fenestration from direct solar radiation has great potential to lower the cooling requirements of building. This can be accomplished in ways that are consistent with ensuring good passive heating performance in winter months by choosing the geometry of the overhangs with care.
- The thermal characteristics of a building are largely influenced by design decisions made by the architect during the preliminary design phase. They consequently have a major role to play in the design of energy efficient and comfortable buildings. Unfortunately, architects hardly ever consider the building thermal efficiency at this stage of the design process. The use of suitable ***thermal mass*** and ***thermal insulation*** is important for energy efficiency. The building materials selected should have minimum environmental impact during their entire life cycle.
- The ***ventilation*** of the building can have a significant effect on energy consumption. Ventilation strategies can greatly reduce energy costs, improve comfort and occupant satisfaction, and reduce negative environmental impacts.
- The colours of the building envelope determine the impact of solar radiation on the building. In effect, this depends on what fraction of solar energy striking the building is actually absorbed at the building envelope, affecting its heat gain and indoor temperature, and what fraction is reflected away, without any effect on the building thermal conditions.
- The amount of solar radiation striking the different walls of a building varies greatly with the wall's orientation. Therefore, in practice, the colours of the walls also determine the quantitative effect of their orientation.
- Climate has a major effect on thermal performance and energy consumption in buildings. Energy conscious design requires an understanding of the climate: the local climate responsive architecture uses special designs to help get the most benefit out of the natural environment. By understanding climatic conditions architects are able to develop climate responsive building designs. The result is a building that utilizes less energy and provides a high quality and comfortable environment for the occupants.

- Bioclimatic architecture has received a fair amount of attention all over the world in the past few years. Bioclimatic architecture is one of the best energy saving measures in building because it can reduce the energy factor. In addition to being better for the environment, it contributes to an independent and sustainable energy future. The general benefits of climate responsive design are given below:

1. To reduce energy consumption in the buildings.
2. To use natural energy instead of mechanical systems and power.
3. To provide a comfortable and healthy environment for people.

- Passive solar design is one approach by which to reduce energy consumption in buildings. Passive solar design strategies:
- When cold discomfort due to under-heated conditions prevails:
  - Minimize heat loss.
  - Utilize heat gain from the sun and internal sources.
- When hot discomfort due to overheated conditions prevails:
  - Prevent heat gain.
  - Maximize heat dissipation.
    - The design of energy efficient building in Libyan climate zones must consider solar heat gain in summer, insulation in winter, and natural ventilation during transitional seasons.
    - Provision of thermal comfort in buildings is an important consideration in the design of buildings for energy efficiency and well-being of occupants. To achieve optimum energy efficiency, designers should evaluate the thermal comfort criteria.
    - There are sharp local contrasts in climatic conditions in Libya. The most striking feature of the climate in Libya is the contrast between sea and desert, between the humid Mediterranean coast and the arid desert regions. Bioclimatic design requires an understanding of the potential climatic benefits of a site, which in turn influences building design and planning. Comprehensive site analysis allows the architect to predict and analyse the potential influence of major physical factors like temperature, insulation, wind and topography on building design.

Reduction in terms of temperature for each room in flat 4 as follows main room by 2.19°C, living room 2.04°C, and kitchen by 2.14°C. Converting this to energy it has been found elsewhere that to decrease the temperature by 1°C for each m^3 it needs approximately 11Watt with normal insulation condition. Moreover, it has been found by adding the mashrabia for each element, the main room would need 21000W to produce this reduction if air conditioning were used, the living room would need 28625W, and the kitchen would need 13513W. Furthermore, translating this to energy costs, each W costs 0.25, by adding mashrabia to these elements it could save 16.476 Libyan dinars per day for just decreasing average of 2°C.

7 Chapter 7 Guidelines for designing in hot arid climates

7.1 Introduction

Energy efficiency in buildings has not been a deeply explored field in developing countries and Libya is no exception. The recent awareness of energy and environmental problems related to architecture calls loudly for a bioclimatic architecture. This chapter reviews the recent residential buildings in Libya which are characterized by low-rise buildings, and reflect the absence of any kind of incentive for energy conscious design. Traditional Libyan houses, in contrast, are known to be environmentally friendly in both their design and structure.

There are a range of additional benefits from energy efficient buildings, including life cycle payback and operational cost reduction. The result of this is to integrate their initial cost with life cycle cost analysis to produce a more holistic understanding of the cost benefits of low energy design. The more energy efficient a building is, the less money it costs to operate that building and this means that any up front construction costs are quickly paid back (Harvey, 2006).

7.2 Residential buildings in Libya

Since 1970, new developments of residential areas in Libya have started to be built, similar to those in other developing countries, taking different architectural and urban forms to the Italian one that was there before 1970. The effects of globalization have brought about major shifts towards new forms of residential buildings that can be characterized as blocks of flats. These buildings are regular with regards to both their plans and elevations, as shown in Figure 7.1, but are often designed without taking sufficient account of the climate and energy use.

Demand for housing in Libya is increasing. This is due to a number of reasons, among them that the gap between the supply and the real demand for housing projects is huge. The cost of construction materials for building the concrete structure of a house made from steel, cement and other materials is increasing. Moreover, in Libya the production of some of these materials is not sufficient to absorb the increasing demands; hence, Libya has to import some of these materials which increase the cost drastically.

Figure 7.1 Typical low rise apartments building in Libyan cities.

The fast growing construction of residential buildings in Libya has been accompanied by a major increase in energy consumption, leading to greater fuel consumption and the need for new power stations. In addition, the more energy consumed, the greater the amount of fuel burned, and thus the greater the air pollution in the country, making energy consumption in residential buildings a core problem in the country.

7.3 Traditional residential buildings

One of the most common building typologies in Libya is the traditional courtyard house. This typology is characterised by a small number of relatively small openings in the external façade or the building, as shown in Figure 7.2, contrasting with a large number of openings that open into the inner courtyard, shown in Figure 7.3. Courtyard houses being designed around a central open courtyard, every house is private, shut off from its surroundings by high and solid walls. The interior is always more important than the exterior. The house surface areas are exposed to the sun, having small windows on the lower storey, but protecting an elaborate complex of windows above, "*Mshrabias".* Additionally, most of these houses have one of two basic categories of wind ventilation structures: the unidirectional wind scoop and the multidirectional wind tower.

Figure 7.2 Openings in the external façade: "Mshrabias".

Figure 7.3 Openings in the inner courtyard.

In large and standard-sized houses, a fountain is located in the middle of the courtyard and freshens the air; trees are also grown in the courtyards of many traditional house see Figure 7.4, to add shade and life to this special area. The height of the traditional house is limited, usually not more than 10m for two storeys. Generally, the living rooms and service rooms are on the ground floor whilst bedrooms are on the upper floor. In big houses, with more than one courtyard, spaces are separated into an area for the owners of the house, another one for guests and a third for servants.

Figure 7.4 Traditional houses.

Courtyards are equipped with many elements that help humidify the air; they also use the "*jalsa*" as an open summer sitting room facing which usually faces north. The thick walls and roofs are good insulators and help in stabilizing room temperatures, while the variable roof heights and protruding elements in the façade provide shade. Some elements which appear in the traditional urban house help to increase the amount of shaded areas, such as:

- The use of protrusions and cornices on the outer facades or on the inner court facades that look over the courtyard.
- Some traditional houses use the roof garden as a way to lessen heat in the house.
- Covered streets protect the walls from direct sunlight.
- Traditional houses in urban areas also contain many architectural elements designed to ensure a natural airflow through all the spaces; A great variety of ceiling heights are used and the main spaces of the house are conceived so as to be ventilated by soothing winds.

7.4 Recent residential buildings

Most of the recent residential buildings in Libya refer to the international style: they are characterized by multi-storey buildings, as illustrated in Figure 7.5, and reflect the absence of any kind of incentives for energy conscious design. These buildings are found in all cities and represent modern construction practice followed in the last 40 years. There are a number of housing units (8-36) or apartments in each building: one family typically occupies one apartment. The typical number of storeys is 4-12 storeys. They are built by developers or the government and sold to the people who live in this type of construction (Awad, Bassam, & Talal, 2003).

Figure 7.5 Recent residential building in Libya.

7.4.1 Construction techniques and materials

In Libya, structural stability in current construction relies basically on the roles played by the columns rather than walls: this makes it possible to reduce the thickness of the building skin see Figure 7.6.

Figure 7.6 Current constructions in Libya.

- Reinforced concrete for the skeleton.
- The external walls are made of 15 to 20 cm thick hollow concrete blocks.
- The roofs are often flat, made of reinforced concert.
- Openings are large, often with clear single glazing.

7.4.2 Energy efficiency and thermal comfort

Since the oil embargo experience in late 1960s, energy efficiency in buildings has become one of the world's major challenges. Energy efficiency in buildings has not been a deeply explored field in developing countries and Libya is no exception to this. The recent awareness of energy and environment problems related architecture and construction draws attention to the need for a climate responsive architecture.

There are no building regulations in Libya concerning energy and environment, there are not even any direct codes or norms for climate design in terms of building materials, orientation and shading devices. These apartment blocks show that the architectural heritage has been forgotten. The same blocks can be found in the desert, inland and in the coastal zone, without taking into consideration the local climate. The above problems have led to worsening the buildings' physical situation, their construction and the energy use.

To compensate for the lack of comfort, huge cooling and heating equipment are installed in dwellings.

7.5 Bioclimatic design checklist for residential building designs in Libya

The Bioclimatic Design checklist is another tool that can assist architects in producing a more energy efficient and less polluting design, and allows the effectiveness of various alternatives to be specifically evaluated for the Libyan zones. (Cheung, Fuller, & Luther, 2005).

7.6 Conclusion

As pointed out above, the fast growing residential building sector in Libya has been accompanied by a great increase in energy consumption. However, most of the existing buildings lack the attractive features of efficient energy buildings. Recent residential buildings are often designed without taking sufficient account of the climate and energy use of both occupants and the building. Since regional versions of traditional architecture can help teach us how to build truly low energy buildings, it is important to preserve some of these old buildings in the community so that local architects and building owners can see for themselves what works in those climate and cultures.

Again, the building design measures examined above in chapter 6 aims at reducing the energy consumption of low rise apartment buildings, and hence CO_2 reduction as strategy to protect the environment. The simulation results in chapter 6 indicate that there is a large potential to significantly reduce energy consumption for heating and cooling by using appropriate building design strategies. Some of the strategies described in this study can be applied to building design by architects and other designers in the early design stages with minimal cost implications. Thus, the selection of an optimum orientation, or the use of white colour for the external walls, the use of shading devices, and choosing the right window ratio and glass colour can be very beneficial.

The results also indicate that the strategies for improving the thermal performance of external walls and selection of appropriate window size are very effective. Additionally, the simulations indicate that solar gains through the windows contribute to the space heating, and it is important to increase the window glass size or area, as a smaller window area could significantly reduce the availability of daylight. It is also suggested that the use of energy simulation tools in building design can assist architects to produce more energy efficient and less polluting designs by evaluating the effectiveness of various available alternatives. The cost of energy is a major component of building operating costs. The LCC analysis encourages energy efficiency by evaluating the total cost of ownership for several competing design alternatives. The results of this study can be integrated with a life cycle cost analysis to produce a more holistic picture of cost benefits of low energy design in the Libyan context.

8 Chapter 8 Conclusions and recommendations for further work

8.1 General Conclusion

This research assessed the thermal energy performance of a domestic building in Tripoli (Libya) with the aim of finding innovative strategies for lowering its energy consumption. In order to carry out this assessment, the building was closely monitored over a period of 45 consecutive days, using computer simulation of a variety of intervention strategies. Appropriate building orientation, materials and better configuration produced suitable solutions and strategies for energy and environmental problems in countries with a hot and arid climate such as Libya.

From the study, it has been observed that the hottest and dry regions in the world are located in the sub-tropical latitudes where apart from rooftops, the eastern and western facades of buildings receive the highest intensity of the sun radiation during summer. Thus, a north-south orientation is favoured for the main building facades, which offers an easy and inexpensive way of shading the southern facades and walls with horizontal overhangs. As can be seen from the results presented in chapter 5, buildings consume a vast amount of energy, and efficient energy use is therefore essential goal, as there are finite global energy resources. Design and construction features and devices which could control solar gain, (heat transmission/ absorption) such as external and internal solar film as well as shading devices when applied on the building has reduced the energy consumption patterns very considerably.

This research has triggered the consideration of numerous policies and regulatory issues and has unearthed the lack of a sustainable energy efficiency policy both in theory and practice, in Tripoli. As a result, there is lack of awareness among the general public, particularly urban dwellers, of the effect of their behavioural patterns and lifestyles on their energy consumption behaviours.

8.2 Specific conclusions

The best design and evaluation method or tool is the environment solution (IES-VE) which has been practically and effectively used in this study to achieve the results as shown in Chapter 5. From the findings, it was established that location and orientation of the building are important factors in determining the amount of energy consumption. The key factor that affects solar gain is the orientation of the building. Hence, building form is an important factor influencing heat gain through the whole building, as cooling energy consumption has a significant influence on energy use. Thus, the orientation, building form, fenestration and construction materials employed in the building all contribute to the energy consumption patterns of the building.

An important point to emerge from this research is that the use of air conditioning is almost universal, and residents are spending large amount on air conditioning. Added to that, conditions are not always comfortable; which shows that air conditioner systems are not well matched to the loads.

The thermal characteristics of a typical building in the case Tripoli are largely influenced by design decisions which consequently have a major role to play in the design of energy efficient and comfortable buildings. From the findings, it was established that there are a lot of heat gains during summer periods in Tripoli and energy consumption patterns therefore increases during such periods.

The findings again, point to the fact that the adoption of bioclimatic architecture is one of the best energy saving measures that can reduce the energy factor of buildings in Tripoli. Also, the adoption of passive solar design is the surest way of reducing the energy consumption in buildings in Tripoli. This will minimize heat loss; utilize heat gain from the sun and internal sources and also maximize heat dissipation in the buildings.

The findings also show external solar film devices are the most suitable mechanism for the reduction of CO2 production by buildings by 11.2%. This is followed by shading devices and the rest may not contribute and significant values in this regards. Surprisingly, the internal film device stands out as being the best device for chiller energy load reduction in buildings by 11.7%. This is followed by external solar film and shading devices by 11.3%. The contribution of emissivity paints and roof absorbers above slab are again insignificant by 11.4%. Finally and more importantly, the application of both external solar film and shading devices would together reduce the effects of energy consumption in buildings significantly.

AS flat 4 has no air conditioning, it was interesting to carry out further analysis and IES simulation. Reduction in terms of temperature for each element as following main room by 2.19°C, living room 2.04°C, and kitchen by 2.14°C, converting this to energy it has been found elsewhere that to decrease the temperature by 1°C for each m^3 it needs approximately 11Watt with normal insulation condition. Moreover, it has been found by adding the mashrabia for each element, the main room would need 21000W to produce this reduction if air conditioning were used, the living room would need 28625W, and the kitchen would need 13513W. Furthermore, translating this to energy costs, each W costs 0.25, by adding mashrabia to these elements it could save 16.476 Libyan dinars per day for just decreasing average of 2°C.

8.3 Recommendations

8.3.1 Policy recommendations

It is worth recommending at this point the need for an energy efficiency policy to be developed and implemented as the first and most important step towards a sustainable energy savings in Tripoli. However, this will requires collaboration between government, professionals, end users and all stakeholders in order to progress with the end goal of benefits for society, the environment and on the individual level for residents. The government needs to adopt policies that aim at reducing greenhouse gas emissions, with renewable energy sources being developed as part of such policy, which would demonstrate the extent of government commitment towards societal development. The government should also set up long-term renewable energy and electricity standards and goals, motivated in the form of energy production payments subsidies, loan assistance, tax credits, the development of tradable market instruments, and leadership by example as well as an intensive user education programme. It is also worth recommending here that government should establish incentive programs, such as: an expedited plan check, reduction in permit fees, rebates on inspection fees, frees marketing, public awards to recognise outstanding projects that utilised energy efficient designs or creative incentives for designers, builders and others who construct highly energy efficient buildings in the country. It is also important to establish and promote reforms in the heating system in order to encourage energy efficiency.

8.3.2 Public awareness recommendations

As the development of energy-efficient buildings and renewable energy applications are highly dependent on people's awareness and understanding of issues, public education has an important role in this direction. Such an activity must target all sectors of society through primary and secondary school education, universities, by providing technology transfer and human education, short courses and workshops, technical and vocational training for architects, and other continuing professional development programmes. Behavioural and lifestyle changes among the public to change their energy consumption and encourage the use of more energy-efficient production are important factors in addressing the challenge of the knowledge gap among households in reducing greenhouse gas emissions. The promotion of energy efficiency should be intensified and must include the promotion of residential and building codes on energy efficiency, as a first step towards sustainable energy consumption among households.

8.3.3 Technical recommendations

Professionals such as architects, engineers and other professionals must incorporate energy design concepts and methods into their design because this can have a significant impact on reducing energy consumption and achieving sustainable energy. This is also because materials specification and construction methods rely on their remits. Specifying the right energy saving materials at the design stages of the project would be very helpful. Designers in the built environment must be encouraged to adopt the use of software to integrate bioclimatic design concepts and principles into energy efficiency in buildings.

8.3.4 End users recommendations

Residential building owners and users should be made aware of the potential financial benefits they stand to gain by using appropriate materials and a suitable architectural design for the local environment in residential building construction. In addition, residents should be informed of the benefits of upgrading their homes with the addition of solar gain control devices and shading, particularly on the east and west sides. Incentives such as a tax reduction on materials for buildings that incorporate thermal control strategies into their design can encourage this process. The overall aim is to raise awareness of the issues, without imposing additional financial burdens on households.

8.4 Further research

The proposed guidelines and recommendations in this research focused on solar gain control design for residential buildings in hot arid regions, using Libya as an example. Based on this study, the following future research is recommended:

- Applying the solar gain control strategies studied to other cities in hot arid regions, as a shading design that is suitable at one latitude, may be completely inappropriate for other sites at different latitudes.
- Examine the relationship between solar gain control strategies and other passive cooling techniques, particularly natural ventilation in the context of the passive thermal performance of residential buildings in hot arid regions.
- There would be value in any research that complements the theoretical and design research, solving various relevant design problems. Connecting the results and recommendations from various research studies and their application in the future residential building design greatly benefit both professionals and the general public.

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Appendixes 1 Questionnaire

Statistics

Personal description

Gender	Male	Female

Age	20-30	30-40	40-50	50-60	60-70

Haw many hour do you work par day outside your home

Working Hours	2-4	4-6	6-8	8-10	10-12

Where are you originally from

From	Coastal city	Desert city	Mountain City	Other

Building Description

Floor

Floor	

How many people live in the house............................?

How many:

Rooms	WC	Living room	kitchen

Orientation of the flat

North	South	East	West

Building Materials

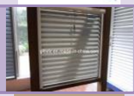
Finishing walls

type	Internal
Added insulation	
Wallpaper	
Painting	

Openings (windows) material

Single glass with wood frame		Single glass with aluminium frame	
Double glass with wood frame		Double glass with aluminium frame	

Type of windows

Sliding windows		
Louvre windows		
Casement		
Awning		
Fixed		

Windows orientations

N	N&E	E	S&E	S	S&W	W	N&W

Thermal Comfort

Temperature in the flat during the day

Time	Cold	Slightly cool	Neutral	Slightly warm	Hot
Morning					
Afternoon					
Evening					

Temperature in the flat during the season

Season	Cold	Slightly cool	Neutral	Slightly warm	Hot
Summer					
Winter					

Haw you cool your house in summer

Opening the windows		Use hand fan	
Air conditions		Electric fan	
Take off layer of clothing		Other	

How many AC you have in your flat

1	2	3	4	5

When you usually turn the air condition on

00:00-06:00	06:00-12:00	12:00-18:00	18:00-24:00

How do you heat your house in winter

Closing the windows		Electric heaters	
Air conditions		Gas heater	
Put on layer of clothing		Other	

Air movement in the room

Do you use natural ventilation in warm summer

Yes	
No	

If NO is it because

Dust	Noise	Air pollution	other

How do you feel about air movement in your house

Light		Gentle	
Strong		Humid	
Other			

Energy Assessment

Do you pay for your electricity

Yes	
No	

How much you pay for your monthly electricity per month in winter

0-50		50-100	
100-150		150-200	
200-250		250->	

How much you pay for you electric per month in summer

0-50		50-100	
100-150		150-200	
200-250		250->	

Are you satisfied or not satisfied with you thermal comfort in

	Yes	No
Winter		
Spring		
Summer		
Autumn		

Have you ever tried any measures to save on your electricity bill?

Yes	
No	

If yes what measures.............................

What is your opinion about Climate Change

Truth	
Myth	

Appendixes 2 Field data

Daily average temperature and energy consumption																
Date	Flat 1			Flat 2			Flat 3				Flat 4				Average	
	°C			°C		kWh	°C			kWh	°C			kWh		
	Main room	Living room	Kitchen	Main room	Living room	Energy consumption flat 1 & 2	Main room	Living room	Kitchen	Energy consumption	Main room	Living room	Kitchen	Energy consumption	Air temperature	Basement
5/7/2013	26.5	26.1	28.9	27.0	27.3	81.85	26.0	26.0	26.3	78.68	26.4	26.4	26.8	12.23	26.6	27.3
6/7/2013	27.9	27.5	29.1	28.6	26.7	56.42	27.5	28.4	28.2	56.18	30.8	31.0	32.1	11.38	26.6	27.4
7/7/2013	27.8	27.6	28.2	28.5	26.6	62.48	27.2	29.2	29.8	38.36	30.7	30.9	31.8	6.04	26.0	27.4
8/7/2013	27.6	27.6	27.5	28.4	27.6	69.35	27.0	29.1	28.6	49.20	30.6	30.8	31.7	5.09	26.1	27.4
9/7/2013	27.5	27.4	27.8	28.5	28.0	73.19	26.2	28.5	24.6	58.55	30.8	30.9	31.7	5.44	27.1	27.4
10/7/2013	27.5	27.3	28.4	28.9	28.4	91.06	27.3	29.0	27.7	52.78	31.4	31.4	32.2	0.06	28.6	27.5
11/7/2013	27.5	27.5	28.5	29.4	28.6	99.84	28.2	29.6	28.9	48.11	32.1	32.0	32.9	0.08	29.8	27.6
12/7/2013	27.5	27.3	27.9	29.4	26.9	144.71	28.4	30.4	29.1	48.64	32.6	32.6	33.5	4.18	29.4	27.7
13/7/2013	28.1	27.1	27.8	29.4	26.3	125.86	29.3	31.0	31.0	52.06	33.0	33.0	33.9	21.81	30.3	27.6
14/7/2013	28.6	27.9	29.3	29.8	26.5	120.49	28.3	31.2	31.0	52.40	33.6	33.4	34.3	26.25	31.6	27.6
15/7/2013	28.7	28.0	28.2	30.3	27.2	148.89	29.3	31.4	30.9	49.84	34.1	34.0	35.0	4.47	30.9	27.7
16/7/2013	28.2	27.2	27.7	29.9	27.0	111.03	29.0	30.6	30.2	41.33	33.5	33.8	34.8	4.66	28.4	27.7
17/7/2013	28.2	27.7	29.1	29.9	27.4	85.87	28.6	30.8	29.6	40.63	32.9	33.3	34.2	4.55	28.1	27.7
18/7/2013	27.8	28.2	30.0	30.0	28.7	50.50	28.4	30.9	29.9	30.80	32.8	33.1	34.0	4.53	29.2	27.8
19/7/2013	27.7	27.5	29.8	30.3	27.9	106.67	28.8	31.1	29.4	36.93	33.1	33.2	34.0	4.42	29.8	28.0
20/7/2013	27.9	27.9	29.7	30.3	27.4	89.8	28.1	31.0	29.1	47.81	33.4	33.3	34.3	4.52	30.3	28.0
21/7/2013	28.0	27.9	30.1	30.7	27.4	132.21	29.1	31.4	29.8	51.89	34.0	33.8	34.8	3.76	32.1	28.1
22/7/2013	28.5	28.0	29.6	31.1	27.5	122.27	29.9	31.9	29.7	42.62	34.7	34.6	35.7	4.70	31.4	28.3
23/7/2013	28.0	27.9	30.3	30.4	27.6	118.16	28.9	30.4	28.0	52.52	34.5	34.6	35.7	4.77	30.1	28.3
24/7/2013	27.6	28.2	30.2	30.2	27.5	109.30	28.6	30.5	27.3	44.37	34.0	34.1	35.2	3.62	29.7	28.2
25/7/2013	27.6	27.8	30.0	30.7	28.7	81.50	29.0	30.0	27.7	38.19	33.7	33.8	34.9	3.72	29.8	28.2
26/7/2013	26.6	27.8	29.7	30.5	28.0	121.33	28.3	30.2	29.2	35.61	33.6	33.7	34.7	3.46	29.7	28.3
27/7/2013	27.4	27.6	28.7	30.4	27.3	121.95	30.7	31.1	30.9	14.89	33.4	33.6	34.6	4.31	29.6	28.2

Appendixes 2 *Field data*

28/7/2013	27.8	27.1	29.6	30.2	27.0	107.59	31.4	31.4	31.7	26.21	33.3	33.7	34.6	10.87	30.0	28.1
29/7/2013	28.0	27.2	28.3	30.2	27.0	130.67	32.1	32.2	32.9	32.28	33.2	33.7	34.7	10.73	29.4	28.1
30/7/2013	27.5	27.3	29.2	30.4	28.2	79.87	31.4	32.1	33.2	31.56	33.1	33.7	34.6	10.76	28.3	28.1
31/7/2013	27.5	27.7	29.3	30.3	28.9	54.15	32.2	32.3	33.5	33.83	32.5	33.3	34.1	10.77	28.3	28.1
1/8/2013	27.6	27.8	29.0	30.3	28.6	57.50	31.8	32.0	33.2	27.79	32.0	32.9	33.6	10.65	28.1	28.1
2/8/2013	27.8	28.0	29.4	30.1	29.0	63.02	32.2	32.2	33.3	28.41	32.1	32.9	33.7	10.79	28.9	28.2
3/8/2013	28.0	28.1	29.2	30.4	29.4	68.97	31.7	31.3	31.9	40.91	32.4	33.2	34.0	10.85	28.9	28.2
4/8/2013	28.2	27.6	28.5	30.4	28.9	82.01	28.0	30.1	30.4	48.11	32.3	33.0	33.9	10.65	29.3	28.3
5/8/2013	27.7	26.8	28.9	30.5	28.7	90.11	29.7	29.2	28.7	20.12	32.4	33.0	33.9	9.79	28.6	28.4
6/8/2013	27.9	27.9	29.0	30.5	29.1	62.11	29.6	30.6	30.3	42.71	32.4	33.0	34.0	10.58	28.5	28.4
7/8/2013	27.7	27.7	29.4	30.5	29.4	84.40	30.6	31.0	31.4	29.96	32.4	33.1	34.0	10.60	28.6	28.4
8/8/2013	27.9	27.2	29.3	30.6	29.4	92.77	29.0	30.4	29.5	50.04	32.7	33.3	34.2	10.84	29.8	28.5
9/8/2013	28.2	27.5	30.0	30.7	29.4	97.72	29.8	30.9	30.6	30.26	32.9	33.3	34.4	6.14	29.7	28.5
10/8/2013	28.3	27.2	30.0	30.2	27.2	85.68	28.0	30.1	27.6	33.55	32.7	33.1	34.3	3.97	28.9	28.5
11/8/2013	27.8	27.2	29.3	30.2	28.6	90.18	27.7	30.4	30.2	22.18	32.2	32.6	33.8	4.26	28.5	28.4
12/8/2013	28.0	27.6	29.2	30.2	28.8	86.85	29.2	30.8	31.5	39.18	32.0	32.4	33.5	0.79	28.3	28.4
13/8/2013	28.1	27.5	29.7	30.2	29.1	61.03	29.2	30.8	31.6	31.15	32.2	32.4	33.5	6.06	28.4	28.2
14/8/2013	28.1	27.4	30.0	30.5	29.4	83.07	30.2	31.0	31.6	30.86	32.7	32.7	33.6	0.72	29.3	28.2
15/8/2013	28.1	27.7	30.0	30.6	29.5	73.95	29.8	31.0	30.9	47.67	32.9	33.0	34.0	4.70	29.1	28.3
16/8/2013	28.3	27.6	29.5	30.4	29.5	97.03	27.5	28.9	28.8	51.83	32.6	33.0	34.0	6.43	28.1	28.5

Appendixes 2 *Field data*

Date	Average North				Average East				Average South				Average West				Average Roof services	Average outside temperature
	Ground		First		Ground		First		Ground		First		Ground		First			
	Wall	Glass	Wall	Glass	Wall	Glass	Wall	Glass	Wall	Glass	Wall	Glass	Wall	Glass	Wall	Glass		
07/07/2013	25.1	24.2	25.0	23.5	25.8	24.4	25.9	24.3	26.7	26.6	27.3	26.9	32.7	29.0	31.9	29.2	36.8	26.0
08/07/2013	22.6	21.5	24.2	21.0	24.3	23.2	23.6	21.1	26.6	26.1	27.0	26.3	27.4	23.6	26.7	21.7	28.7	26.0
09/07/2013	27.8	27.4	27.7	27.0	31.5	29.0	31.3	30.1	28.4	28.5	28.8	29.2	32.4	31.9	31.7	30.1	41.3	27.1
10/07/2013	29.6	30.5	29.7	29.6	33.5	34.4	32.6	31.3	29.4	29.0	30.0	29.5	34.0	34.9	34.0	32.1	41.8	28.6
11/07/2013	29.8	30.3	30.2	29.5	32.4	32.6	32.0	30.9	30.1	29.3	30.0	30.0	33.4	33.6	33.7	31.3	39.4	29.8
12/07/2013	29.7	29.2	29.3	28.2	31.9	31.0	32.1	30.6	30.2	29.3	30.4	29.9	33.5	32.8	32.8	31.3	41.0	29.4
13/07/2013	29.7	29.8	29.8	28.7	32.6	31.0	32.8	30.3	30.6	29.7	30.7	30.3	33.6	33.5	32.9	31.7	40.3	30.3
14/07/2013	31.3	31.5	31.2	30.1	34.4	34.0	34.2	33.5	31.9	30.9	32.3	31.9	35.2	35.6	34.6	33.0	41.4	31.6
15/07/2013	28.9	29.3	29.2	28.6	31.2	29.4	30.4	29.7	30.8	29.7	31.1	31.2	34.7	31.5	32.3	31.8	37.5	30.9
16/07/2013	27.8	27.8	28.2	27.2	31.0	29.0	30.3	29.9	29.8	28.7	30.0	29.1	32.5	31.2	30.9	31.2	40.6	28.4
17/07/2013	26.7	26.7	27.2	25.9	30.2	30.4	30.0	28.7	28.7	28.2	29.5	28.7	32.2	30.6	30.7	30.8	38.1	28.1
18/07/2013	28.0	28.7	28.3	27.0	31.2	29.0	30.6	30.1	29.9	29.1	30.0	29.2	33.4	33.4	31.6	33.0	39.6	29.2
19/07/2013	28.9	29.7	29.3	29.0	32.4	31.1	32.2	32.2	30.1	29.2	30.4	29.9	32.9	32.2	31.9	32.8	39.5	29.9
20/07/2013	29.6	30.2	30.1	29.5	32.2	31.6	32.0	31.7	30.6	29.7	31.0	30.8	34.0	33.5	32.8	33.0	39.8	30.3
21/07/2013	31.2	32.0	31.4	30.7	35.0	34.1	34.9	33.3	32.5	31.3	33.0	32.5	35.9	35.9	34.7	35.1	41.7	32.1
22/07/2013	29.8	30.0	30.4	29.8	33.1	33.1	32.8	31.2	31.6	30.5	32.2	31.9	34.8	35.4	33.9	33.4	39.7	31.4
23/07/2013	29.5	29.1	29.0	28.7	32.0	30.5	30.0	29.7	30.8	30.0	30.7	30.6	32.4	30.9	32.1	30.8	38.5	30.0
24/07/2013	29.2	29.1	29.2	29.0	31.0	31.3	31.0	30.2	30.6	29.8	30.8	30.2	32.6	32.9	32.0	30.9	39.3	29.7
25/07/2013	29.7	29.9	29.0	28.8	31.9	31.0	31.7	29.1	30.4	29.8	30.7	30.8	32.4	33.7	32.8	31.6	38.7	29.8
26/07/2013	29.6	29.0	29.0	28.1	32.0	31.1	29.9	30.0	30.6	29.8	30.2	30.1	33.0	32.6	32.9	31.2	39.2	29.7
27/07/2013	28.5	28.5	29.0	27.6	32.1	30.7	30.7	31.0	30.5	29.6	30.2	29.9	33.5	32.5	32.2	30.9	40.2	29.6
28/07/2013	28.8	29.3	29.0	27.7	30.3	30.4	31.4	30.1	30.8	29.7	30.0	30.4	32.6	33.9	32.3	31.4	38.3	30.0
29/07/2013	28.3	28.5	29.1	28.2	31.8	30.4	32.0	31.3	30.5	30.1	30.3	30.6	33.4	32.6	32.2	31.7	39.1	29.4
30/07/2013	28.2	28.3	29.1	28.5	32.2	32.0	32.6	32.8	29.5	29.0	29.9	30.6	31.7	30.0	30.9	30.3	37.9	28.3
31/07/2013	28.3	28.3	28.4	28.2	31.4	30.2	32.1	31.2	29.1	29.0	29.8	31.0	30.9	29.7	29.8	29.2	35.5	28.3
01/08/2013	27.7	27.7	28.0	27.9	30.4	29.7	31.3	31.9	28.9	28.8	29.5	30.1	31.2	31.6	30.4	30.4	37.1	28.1
02/08/2013	28.4	28.8	29.0	28.9	31.7	30.8	32.0	31.2	29.8	29.5	30.1	31.2	33.2	32.4	32.1	32.1	35.9	28.9

03/08/2013	**28.8**	**29.4**	**29.3**	**29.0**	**31.6**	**30.8**	**31.8**	**31.6**	**29.9**	**29.6**	**30.4**	**31.0**	**32.9**	**32.2**	**32.0**	**31.8**	**37.4**	**28.9**
04/08/2013	**28.7**	**28.8**	**28.9**	**28.4**	**31.7**	**30.8**	**31.4**	**32.3**	**30.3**	**30.2**	**30.3**	**31.2**	**32.5**	**31.8**	**31.8**	**31.8**	**38.5**	**29.3**
05/08/2013	**28.5**	**28.8**	**28.6**	**29.4**	**32.0**	**31.4**	**31.7**	**32.1**	**30.0**	**29.0**	**29.5**	**30.7**	**32.1**	**31.1**	**31.0**	**31.8**	**37.2**	**28.6**
06/08/2013	**28.0**	**28.3**	**28.6**	**28.3**	**31.5**	**30.0**	**31.6**	**32.0**	**29.4**	**29.2**	**29.7**	**31.0**	**32.7**	**32.2**	**31.7**	**31.4**	**37.5**	**28.5**
07/08/2013	**28.5**	**28.1**	**28.5**	**28.2**	**31.7**	**30.0**	**32.0**	**31.8**	**29.5**	**29.3**	**29.8**	**31.0**	**32.9**	**31.2**	**31.4**	**31.8**	**39.1**	**28.6**
08/08/2013	**28.6**	**29.1**	**29.1**	**28.5**	**33.1**	**32.3**	**32.9**	**32.8**	**30.4**	**29.6**	**30.1**	**30.7**	**32.8**	**32.1**	**31.6**	**32.2**	**39.4**	**29.8**
09/08/2013	**27.7**	**28.3**	**28.3**	**28.3**	**32.2**	**31.1**	**32.0**	**30.9**	**30.6**	**29.8**	**30.3**	**31.1**	**32.7**	**32.3**	**31.2**	**31.7**	**40.3**	**29.7**
10/08/2013	**28.4**	**28.2**	**28.6**	**28.1**	**32.2**	**30.9**	**32.4**	**32.2**	**29.7**	**29.1**	**30.4**	**30.8**	**32.0**	**31.4**	**31.0**	**30.2**	**37.9**	**28.9**
11/08/2013	**28.2**	**28.1**	**28.5**	**27.6**	**32.7**	**31.5**	**33.1**	**32.2**	**29.2**	**29.0**	**30.4**	**30.9**	**31.6**	**30.3**	**30.8**	**30.9**	**38.0**	**28.5**
12/08/2013	**28.1**	**29.2**	**28.6**	**28.1**	**31.9**	**31.0**	**32.5**	**32.1**	**29.2**	**28.8**	**30.2**	**30.8**	**32.3**	**31.5**	**31.3**	**31.2**	**37.7**	**28.3**
13/08/2013	**27.5**	**27.7**	**28.0**	**26.8**	**31.6**	**29.8**	**32.1**	**31.5**	**29.5**	**29.1**	**29.7**	**30.4**	**32.1**	**31.5**	**31.2**	**30.8**	**39.8**	**28.4**
14/08/2013	**28.0**	**28.6**	**28.8**	**27.8**	**32.1**	**30.8**	**31.9**	**32.9**	**30.0**	**29.7**	**30.0**	**31.4**	**33.4**	**32.9**	**31.8**	**32.2**	**38.2**	**29.3**
15/08/2013	28.2	28.6	29.0	28.1	32.3	31.0	33.1	31.9	30.2	29.5	30.5	31.1	33.2	32.1	31.9	31.9	40.1	29.1

Date	Time	Air Temperature ^oC	In side Humidity %	Outside Humidity %
07/07/2013	00:00			
	02:00			
	04:00			
	06:00			
	08:00			
	10:00			
	12:00			
	14:00	27.5	62.8	65.5
	16:00	28.7	38.8	58
	18:00	28.1	47.8	61.4
	20:00	25.9	54.5	70.9
	22:00	23.7	61.1	80.4
08/07/2013	00:00	24.3	58.7	78.5
	02:00	24.2	60.1	77
	04:00	24.1	62.5	72
	06:00	24.3	65.8	75
	08:00	24.4	68.7	78
	10:00	24.6	70	75
	12:00	27.5	68	78
	14:00	28.4	68	77
	16:00	27.1	67	76
	18:00	26.1	66	76
	20:00	24.8	65	75.8
	22:00	24.8	64	75.8
09/07/2009	00:00	23.8	75.6	83.5
	02:00	23.9	74.3	81.5
	04:00	24	72.9	79.5
	06:00	24.2	71.5	77.5
	08:00	24.3	70.1	75.5
	10:00	26.8	48.9	59
	12:00	29.8	40.8	47.3
	14:00	30.6	46.7	34.3
	16:00	31.4	32.6	31.3
	18:00	30.8	31.3	30.3
	20:00	27.2	44.2	42.8
	22:00	26.8	50.4	48.9
10/07/2013	00:00	26.4	56.5	55.1
	02:00	26.3	55.1	54.9
	04:00	26.2	53.6	54.7
	06:00	26.3	51.5	54.5
	08:00	26.4	50.8	54.3
	10:00	28.2	44.9	48.1
	12:00	30	39.1	41.8
	14:00	31.4	33.2	35.6
	16:00	32.7	27.3	29.4
	18:00	32.1	29.2	31
	20:00	25.5	40.5	43.7
	22:00	28	36.3	39.8
11/07/2013	00:00	27	47.7	49.2
	02:00	25.9	45.4	48
	04:00	26.1	44	46
	06:00	26.9	42	44.9
	08:00	27.5	42.4	43
	10:00	29.6	37.5	38
	12:00	31.6	32.6	32.9
	14:00	33.7	27.7	27.9
	16:00	35.7	22.7	22.8
	18:00	27.7	48.9	65.1
	20:00	28.5	43.8	60.7
	22:00	27.4	65	71.9
12/07/2013	00:00	26.5	59.9	77.1
	02:00	27.9	55.2	72.3
	04:00	26.3	94.4	73.9
	06:00	26.1	80.3	68.3
	08:00	26	70.1	62.6
	10:00	28.8	42	38.7

	12:00	31.4	43.5	40.5
	14:00	33.5	30.4	35
	16:00	26.6	39.9	41.2
	18:00	32.1	29.7	31.3
	20:00	30.2	31.7	32.5
	22:00	27	42.3	45.6
13/07/2013	00:00	27.7	45.8	47.4
	02:00	26.9	37	40.6
	04:00	27.5	34	34.2
	06:00	28.7	32	34.1
	08:00	30.1	29.7	29.9
	10:00	31.5	27	27
	12:00	33.2	26.4	26.8
	14:00	34.2	24	25
	16:00	26.5	38.7	41.6
	18:00	33.4	27.6	28.9
	20:00	28.9	36.1	35.9
	22:00	28.8	34.4	33.7
14/07/2013	00:00	28.7	32.6	31.4
	02:00	26.2	36.2	35.2
	04:00	27.5	34.1	34.2
	06:00	28.8	31.9	33.1
	08:00	30	29.8	29.9
	10:00	31.3	27.7	26.8
	12:00	34.9	23	22.4
	14:00	38.4	18.2	17.9
	16:00	29.8	36.5	29.2
	18:00	33.2	26.2	28.8
	20:00	32.6	29.8	35.4
	22:00	30.6	29.1	47.3
15/07/2013	00:00	30.5	28.8	39.4
	02:00	30.5	28.4	31.4
	04:00	29.5	35.6	37.1
	06:00	30.8	30.1	32.2
	08:00	31.6	31	34.5
	10:00	32.4	31.5	40.1
	12:00	33.2	32.1	45.3
	14:00	34	32.9	50.2
	16:00	30.7	45.6	53.2
	18:00	27.3	60.2	67.2
	20:00	28.4	59	64.6
	22:00	27.6	57.9	71.6
16/07/2013	00:00	26.7	56.4	73.9
	02:00	25.7	55.5	76.2
	04:00	26.8	41.9	80
	06:00	26.4	51.2	61.5
	08:00	26.2	56.6	76.2
	10:00	26	64.4	73.7
	12:00	30.1	59.3	64.8
	14:00	33.5	33.5	46.7
	16:00	30.6	37.8	57.8
	18:00	29.8	48	65.1
	20:00	27.9	44.6	73.4
	22:00	27.3	44.8	70.2
17/07/2013	00:00	26	50.4	74.8
	02:00	24.8	55.9	79.4
	04:00	25.5	43.9	74.8
	06:00	26.1	49.5	65.3
	08:00	26.8	55.9	66.8
	10:00	27.2	61.5	67.5
	12:00	29	52.1	54.1
	14:00	30.9	42.6	40.6
	16:00	28.7	55.5	49.5
	18:00	28.4	55.1	54.8
	20:00	28.2	54.7	60.5
	22:00	27.4	56.9	66
18/07/2013	00:00	27.7	60.3	65.9
	02:00	27.9	63.6	65.8
	04:00	25.6	67.4	66
	06:00	26.2	56.7	57.9
	08:00	27.3	45.6	49.3

	10:00	28.5	36.7	32.5
	12:00	29.3	40.1	37.8
	14:00	30	43.5	43.1
	16:00	33.1	29.8	27.5
	18:00	31.5	30	29.2
	20:00	28.3	49.1	50.9
	22:00	27.2	45	47
19/07/2013	00:00	27	43	45
	02:00	28	42.7	43.6
	04:00	26.8	46.9	48.2
	06:00	27	40	43
	08:00	28	37	37
	10:00	29.4	32.7	31.5
	12:00	33.4	25.7	24.5
	14:00	30.4	38.3	38.1
	16:00	34.5	22.6	24.2
	18:00	26	37.8	40.4
	20:00	30.4	38	36.5
	22:00	29	39.1	46.8
20/07/2013	00:00	28	41.7	47.8
	02:00	27	44.2	48.7
	04:00	26.2	41.3	48.2
	06:00	26.3	67.5	84.3
	08:00	27.6	35.6	38.8
	10:00	29.9	43	46
	12:00	34.8	40.1	44.2
	14:00	36	23.6	23.7
	16:00	31.4	36.8	36.2
	18:00	29.5	37.4	46.5
	20:00	27.5	37.8	56.2
	22:00	29.9	39.8	41.8
21/07/2013	00:00	28.4	25.8	40.9
	02:00	27.6	30	37
	04:00	28.8	29	33.2
	06:00	30	28	32
	08:00	32	26	29
	10:00	34.2	20	23.2
	12:00	36	23	25
	14:00	37	20	22
	16:00	38	16	17.6
	18:00	36.8	18	19.7
	20:00	27.1	32	35.7
	22:00	33.6	24.7	25.5
22/07/2013	00:00	32.2	31.1	36.5
	02:00	30.8	28.7	30.4
	04:00	27	35.2	35
	06:00	28.5	36.4	38
	08:00	29.6	37.9	41.5
	10:00	30.8	38	52.5
	12:00	33.7	30.6	38.9
	14:00	28.4	36.5	27.9
	16:00	28.7	35.4	49.9
	18:00	31.4	36.3	45.7
	20:00	28.1	48.1	54.5
	22:00	28.7	53	68.2
23/07/2013	00:00	27.8	50.1	65.2
	02:00	27	51	63.8
	04:00	27	49.2	60.3
	06:00	25.7	49.9	58.7
	08:00	28	45.6	51.7
	10:00	30.3	39.9	44.7
	12:00	32.6	32.4	37.7
	14:00	34.9	24.9	30.7
	16:00	29.3	34.1	44.9
	18:00	29.4	40.9	47.8
	20:00	29.4	47.8	50.7
	22:00	28.4	48.8	50.4
24/07/2013	00:00	28.8	49.7	62.2
	02:00	26.7	37.7	65.2
	04:00	25.9	46.4	75.4
	06:00	26.4	43.3	68

	08:00	26.9	40.1	60.6
	10:00	30.2	36.9	56.5
	12:00	33.5	33.8	52.4
	14:00	33	35.1	45
	16:00	32.6	36.4	37.8
	18:00	30.2	45.5	51.5
	20:00	29.6	51.5	54.2
	22:00	28.4	58.2	63.5
25/07/2013	00:00	27.6	49.5	65
	02:00	26.8	40.7	66.5
	04:00	27	38.5	62.8
	06:00	28	39.5	49.9
	08:00	28.9	36.1	47.1
	10:00	29.7	36	34.9
	12:00	31.5	35.1	35.1
	14:00	33.5	36.1	34.8
	16:00	34.7	37.1	32.6
	18:00	29.6	42.3	47.2
	20:00	29.3	45.7	57.6
	22:00	27.6	53.3	69.8
26/07/2013	00:00	27.5	50.3	66.8
	02:00	27.1	46.5	63.2
	04:00	26.8	39.9	49.9
	06:00	25.7	50.6	61.4
	08:00	27.8	46.2	52.7
	10:00	29.9	41.7	43.9
	12:00	32	37.3	35.2
	14:00	34.1	32.8	26.4
	16:00	28.8	34.7	36.4
	18:00	27.2	32.4	35.8
	20:00	27.8	43.2	58.6
	22:00	27.9	48	62.2
27/07/2013	00:00	27.9	43.6	54.6
	02:00	26	56	67.8
	04:00	27.5	41.4	53.4
	06:00	24.9	61.2	70.8
	08:00	26.1	49.5	65.3
	10:00	26.8	55.9	66.8
	12:00	27.2	61.5	67.5
	14:00	29	52.1	54.1
	16:00	27.3	34.5	32.4
	18:00	32.2	28.7	33.5
	20:00	27.5	35.9	38.5
	22:00	28.7	40.5	45.7
28/07/2013	00:00	26.6	34.5	34.5
	02:00	26.3	34.4	34.3
	04:00	26.2	33.2	35.6
	06:00	26.6	35.6	38.8
	08:00	25.9	43	46
	10:00	26.8	40.1	44.2
	12:00	27.5	37.2	40.1
	14:00	27.9	36.5	35.2
	16:00	34.1	24.2	24.2
	18:00	26.4	33.1	33.8
	20:00	29.9	28.3	30.2
	22:00	26.2	36.9	45.2
29/07/2013	00:00	28.1	40.6	52.5
	02:00	25.8	46.1	67.2
	04:00	26	39.9	70.7
	06:00	26.1	49.5	65.3
	08:00	26.8	55.9	66.8
	10:00	27.2	61.5	67.5
	12:00	29	52.1	54.1
	14:00	32.3	32	52
	16:00	32.6	40.3	51.2
	18:00	28	48.8	60.9
	20:00	29.3	52.6	64.6
	22:00	26.8	48.8	70.9
30/07/2013	00:00	26.2	41	77.6
	02:00	25.3	56.5	81.1
	04:00	26.2	39.8	78.3

	06:00	24.3	67.5	84.3
	08:00	26.6	35.6	38.8
	10:00	25.9	43	46
	12:00	26.8	40.1	44.2
	14:00	27.5	37.2	40.1
	16:00	28.2	48.2	70.1
	18:00	27	45.5	74.3
	20:00	27.4	68.4	75.9
	22:00	26.6	48.5	74.4
31/07/2013	00:00	26	59.6	84.6
	02:00	26.7	46	68.2
	04:00	25.2	52.6	79
	06:00	24.7	65	76.5
	08:00	27.2	50.4	67
	10:00	28	46.8	66.1
	12:00	29.2	40.9	63.8
	14:00	28.7	43.5	62.9
	16:00	27	47.7	61.8
	18:00	29.8	45	57.7
	20:00	27.6	66.4	70
	22:00	27.4	57.9	72
01/08/2013	00:00	25.8	59.8	75.5
	02:00	26.9	42.5	62.8
	04:00	24.3	48.6	80.9
	06:00	23.8	72.2	81.4
	08:00	24	63.9	76.6
	10:00	25.3	55.6	71.7
	12:00	26.1	47.3	66.8
	14:00	26.8	38.9	61.9
	16:00	31.4	39	53.4
	18:00	27.3	47.8	59.8
	20:00	27.7	57	70.9
	22:00	27.3	55.2	73.5
02/08/2013	00:00	26.4	62.5	75.6
	02:00	27.6	50.7	65.4
	04:00	25.9	52.6	81.5
	06:00	27	47.5	77.3
	08:00	26.1	49.5	65.3
	10:00	26.8	55.9	66.8
	12:00	27.2	61.5	67.5
	14:00	30.1	52.1	54.1
	16:00	31.3	39.2	56.8
	18:00	27.5	43.4	59.5
	20:00	28.6	49.2	62.2
	22:00	26.3	52.4	71.2
03/08/2013	00:00	27.5	65.6	74.7
	02:00	27.6	57.5	67.5
	04:00	25.7	72.2	80.4
	06:00	27.1	49.8	70
	08:00	27.2	61	76.4
	10:00	26.9	47.8	70.8
	12:00	29.1	45.8	62
	14:00	32.3	69.9	51.4
	16:00	31.8	40.6	49.7
	18:00	30.5	56.3	58.2
	20:00	28.5	65	66.9
	22:00	27.8	69.6	72.4
04/08/2013	00:00	27.1	61.4	77.2
	02:00	26.7	55.5	79
	04:00	26.2	51.6	71.2
	06:00	25.5	71.1	81.1
	08:00	26	64.5	70.5
	10:00	26.5	59	60.8
	12:00	27	53	59
	14:00	28.5	50	56
	16:00	27.5	45.7	51
	18:00	31	46.3	55.4
	20:00	27.9	52.8	69.8
	22:00	27.4	56.4	26.9
05/08/2013	00:00	26.3	58.9	54.2
	02:00	25.2	61.5	81.5

	04:00	25.9	42.6	78.9
	06:00	23.9	65.4	82.9
	08:00	25.4	64.5	70.5
	10:00	27.9	50	60.8
	12:00	29.5	37	47.5
	14:00	28.5	43	53.2
	16:00	27.5	49	58.9
	18:00	30.7	38.1	53.4
	20:00	25.6	41.5	67.3
	22:00	27.2	56.1	74.6
06/08/2013	00:00	26.7	67.1	74.1
	02:00	26.8	60.8	78.4
	04:00	25.8	41.4	69.6
	06:00	24.1	84.2	85.9
	08:00	27.2	61	76.4
	10:00	26.9	47.8	70.8
	12:00	29.1	45.8	62
	14:00	27.3	69.9	51.4
	16:00	32.5	42.8	45
	18:00	27.2	50.4	60.7
	20:00	28.8	44.4	47.5
	22:00	27.5	49.6	60
07/08/2013	00:00	26.4	58	70.1
	02:00	25.7	56.8	67.6
	04:00	26.3	40.5	64.4
	06:00	23	66.1	73
	08:00	27.2	45.2	52
	10:00	28.7	42.1	47.1
	12:00	30.3	39	42.2
	14:00	31.8	35.9	37.3
	16:00	33.3	32.9	32.3
	18:00	26.2	39.3	65.7
	20:00	27	50.6	59.9
	22:00	28	55.4	64.1
08/08/2013	00:00	27	27.1	81.6
	02:00	25.5	67.1	76.7
	04:00	27.5	49.3	63.9
	06:00	24.6	65	79.6
	08:00	27	53	63.5
	10:00	29.5	50	60
	12:00	26.5	43	55
	14:00	34.7	40	50
	16:00	35.1	35	45
	18:00	28.5	39.4	40.9
	20:00	27.5	42.2	49.9
	22:00	27.9	61.1	65.5
09/08/2013	00:00	27.5	48.9	68.9
	02:00	26.7	55.6	65.8
	04:00	27.6	51.2	51.8
	06:00	27.8	45.6	46.5
	08:00	28.9	40.5	42.4
	10:00	30.8	36.8	40.2
	12:00	32.1	34.6	38.3
	14:00	33.8	30	35.5
	16:00	29.8	46.4	46.2
	18:00	31.7	42.4	59.9
	20:00	26.3	51.7	77.8
	22:00	28.5	45.6	72.4
10/08/2013	00:00	27	46.7	77.1
	02:00	26.7	40.6	75.3
	04:00	27.2	42.7	66.9
	06:00	27.8	40.5	61.5
	08:00	28.1	40.1	56.8
	10:00	28.8	41.2	52.5
	12:00	29.5	42.1	51.2
	14:00	29.1	42.4	50.6
	16:00	28.5	43.4	53.3
	18:00	28.8	42.2	52
	20:00	26.9	48	58.3
	22:00	26.8	54.9	63.2
11/08/2013	00:00	26.2	50	67.2

	02:00	26.1	46.5	64.6
	04:00	26.7	48.9	58.2
	06:00	26.6	54.1	60.6
	08:00	26.5	59.2	62.9
	10:00	28.3	50	57.8
	12:00	28	50	60.3
	14:00	30.2	41.7	52.3
	16:00	27.1	49.7	66.8
	18:00	29.9	44.3	57.3
	20:00	26.6	51.4	63.5
	22:00	27	54.1	68.9
12/08/2013	00:00	26.3	43.5	67.5
	02:00	25.6	59.1	75.6
	04:00	26.9	52	63.7
	06:00	23.9	62.2	68.3
	08:00	25.9	66	74.1
	10:00	27.7	61.3	68.8
	12:00	27.4	60.2	65.2
	14:00	31.5	41.7	50.7
	16:00	27.3	53.4	62.8
	18:00	30.4	47.8	57.8
	20:00	27	50.7	69.8
	22:00	26.8	62.1	72.8
13/08/2013	00:00	26.6	44.1	69.5
	02:00	25.3	62.8	76
	04:00	26.4	53.2	73.2
	06:00	27.5	43.5	70.4
	08:00	27.7	48.8	74
	10:00	29.3	48.7	66.9
	12:00	30.9	48.5	59.8
	14:00	27.7	60.3	66.3
	16:00	31.9	36.3	42.5
	18:00	30.9	39.4	47.2
	20:00	26.3	53	63.2
	22:00	27.6	60.9	72.4
14/08/2013	00:00	26.5	57.9	73.2
	02:00	26.1	67.2	73.7
	04:00	26	66.4	69.8
	06:00	26.1	65.1	68.4
	08:00	26.2	64.9	67.8
	10:00	27.3	53.1	57.1
	12:00	30.1	43.7	48.9
	14:00	32.8	34.2	40.7
	16:00	30.7	47.9	43.2
	18:00	34.3	31	34.4
	20:00	26.8	48.4	58.2
	22:00	28.4	53	71
15/08/2013	00:00	27.2	65.5	53.4
	02:00	26.9	55.8	72.5
	04:00	27.2	54.9	69.4
	06:00	27.4	54	66.2
	08:00	27.6	53.1	63
	10:00	27.8	52.2	59.8
	12:00	27.2	50.4	63.7
	14:00	31.2	41.5	53.5
	16:00	28.7	47.6	53.8
	18:00	28.9	53.6	60.4
	20:00	29.1	59.5	67
	22:00	28.2	48.8	69.4

Appendixes 3 IES software data and training certificate

Virtual Environment 2013

Project File: After.mit
Sim File: low_glass_e_inside.aps 29/Sep/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: lower_sol_ab_roof.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: lower_e_roof.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: trans_lower.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: before.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: after.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw

		Total system energy (kW)	Total system energy (kW)	Total system energy (kW)	Total system energy (kW)	Total system energy (kW)	Total system energy (kW)
		low_glass_e_inside.aps	lower_sol_ab_roof.aps	lower_e_roof.aps	trans_lower.aps	before.aps	after.aps
Date	**Time**						
Wed, 21/Jul	**00:30**	11.8488	11.9147	11.9197	12.0668	19.9392	21.6048
	01:30	14.5900	17.6901	17.6947	11.8079	20.6609	15.5310
	02:30	20.5939	20.7121	20.7163	20.6576	12.6531	12.2704
	03:30	14.6164	11.7121	11.7158	17.6831	12.2374	17.9536
	04:30	11.3995	11.4218	11.4251	11.5490	20.9538	20.8644
	05:30	14.1639	17.2249	17.2279	12.3768	17.9269	11.8349
	06:30	20.3568	20.4139	20.4167	20.3343	11.9943	12.8306
	07:30	21.3441	18.3177	18.3206	21.2530	20.3022	22.0830
	08:30	13.1954	13.0826	13.0855	15.0764	23.6866	23.4854
	09:30	16.3061	17.3497	19.2799	14.4135	24.4864	24.1394
	10:30	22.4578	22.4742	22.5130	22.4188	23.8270	17.2979
	11:30	22.4863	22.5231	22.5467	22.5216	16.1733	21.0665
	12:30	16.6663	18.6577	13.7300	18.6730	25.1474	24.3170
	13:30	14.7562	13.7890	17.7524	13.8291	25.4895	24.6261
	14:30	22.7451	20.8587	22.8652	22.8763	25.9984	24.9114
	15:30	23.0731	23.1068	22.0743	23.2338	20.6875	16.4834
	16:30	16.4145	19.4287	14.5419	17.6314	19.0825	20.9622
	17:30	14.3689	14.5055	17.3670	14.6046	26.9366	26.1033
	18:30	22.9445	20.0551	23.1503	21.2735	26.3458	24.5207
	19:30	19.3009	22.4547	19.5311	22.5814	17.9278	15.3167
	20:30	12.9333	16.1860	13.1557	15.2767	14.9649	14.3173
	21:30	16.7151	12.9402	15.8164	13.0356	20.4243	22.9089
	22:30	21.6135	18.6837	21.7783	19.8681	23.2202	22.7616
	23:30	17.5831	21.6749	18.7532	21.7588	17.0414	13.6403

Virtual Environment 2013

Project File: After.mit
Sim File: low_glass_e_inside.aps 29/Sep/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: lower_sol_ab_roof.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: lower_e_roof.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: trans_lower.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: before.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: after.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw

		Chillers load (kW)	Chillers load (kW)	Chillers load (kW)	Chillers load (kW)	Chillers load (kW)	Chillers load (kW)
		low_glass_e_inside.aps	lower_sol_ab_roof.aps	lower_e_roof.aps	trans_lower.aps	before.aps	after.aps
Date	**Time**						
Wed, 21/Jul	**00:30**	3.9257	4.1411	4.1506	4.2657	12.1810	11.5060
	01:30	5.7652	7.9646	7.9732	4.0701	9.7235	7.1188
	02:30	9.6359	9.7795	9.7874	9.8858	5.3248	4.8062
	03:30	5.4056	3.5548	3.5615	7.6162	4.9016	8.4511
	04:30	3.1577	3.2830	3.2892	3.3343	10.4514	10.0441
	05:30	4.9897	7.1099	7.1156	5.1326	8.0939	3.7728
	06:30	9.1984	9.2273	9.2326	9.2653	4.2320	5.9226
	07:30	10.9000	8.7487	8.7542	10.7581	12.8617	12.5526
	08:30	6.3265	6.2000	6.2055	6.1887	15.3786	14.9427
	09:30	8.9253	10.9084	10.9086	8.8666	16.7739	16.0804
	10:30	13.1324	13.1726	13.1687	13.1713	15.5150	10.3804
	11:30	13.0572	13.1353	13.1334	13.1585	11.9489	14.2271
	12:30	9.2263	9.3255	7.3457	9.3814	18.2703	16.5561
	13:30	9.4884	7.6051	11.6267	7.7058	18.7223	17.0437
	14:30	13.7709	13.8753	13.8828	14.0181	19.5911	17.5120
	15:30	14.1637	14.2834	12.2766	14.4666	16.7140	12.4423
	16:30	8.6736	10.7750	8.7966	10.9938	17.5359	17.5737
	17:30	8.7550	8.9074	10.9202	9.1542	21.5715	19.8818
	18:30	14.1360	12.3741	14.4086	14.6375	20.2519	16.7945
	19:30	10.6323	13.0322	11.0257	13.2691	11.4712	10.1782
	20:30	5.9331	8.2880	6.3142	6.5427	9.8122	8.6797
	21:30	9.7126	6.0242	8.0347	6.2496	13.0670	14.0566
	22:30	11.5334	9.8149	11.8440	12.0195	14.4733	13.5447
	23:30	7.3222	11.5814	9.5724	11.7372	9.9041	7.1108

Virtual Environment 2013

Project File: After.mit
Sim File: low_glass_e_inside.aps 29/Sep/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: lower_sol_ab_roof.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: lower_e_roof.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: trans_lower.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: before.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: after.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw

		Chillers energy (kW)	Chillers energy (kW)	Chillers energy (kW)	Chillers energy (kW)	Chillers energy (kW)	Chillers energy (kW)
		low_glass_e_inside.aps	lower_sol_ab_roof.aps	lower_e_roof.aps	trans_lower.aps	before.aps	after.aps
Date	**Time**						
Wed, 21/Jul	**00:30**	1.5703	1.6564	1.6602	1.7063	4.8724	4.6024
	01:30	2.3061	3.1858	3.1893	1.6280	3.8894	2.8475
	02:30	3.8544	3.9118	3.9150	3.9543	2.1299	1.9225
	03:30	2.1623	1.4219	1.4246	3.0465	1.9607	3.3804
	04:30	1.2631	1.3132	1.3157	1.3337	4.1806	4.0176
	05:30	1.9959	2.8440	2.8462	2.0530	3.2376	1.5091
	06:30	3.6794	3.6909	3.6930	3.7061	1.6928	2.3690
	07:30	4.3600	3.4995	3.5017	4.3032	5.1447	5.0210
	08:30	2.5306	2.4800	2.4822	2.4755	6.1515	5.9771
	09:30	3.5701	4.3634	4.3634	3.5466	6.7096	6.4321
	10:30	5.2530	5.2690	5.2675	5.2685	6.2060	4.1522
	11:30	5.2229	5.2541	5.2533	5.2634	4.7796	5.6908
	12:30	3.6905	3.7302	2.9383	3.7526	7.3081	6.6224
	13:30	3.7954	3.0420	4.6507	3.0823	7.4889	6.8175
	14:30	5.5083	5.5501	5.5531	5.6072	7.8364	7.0048
	15:30	5.6655	5.7133	4.9106	5.7866	6.6856	4.9769
	16:30	3.4694	4.3100	3.5186	4.3975	7.0144	7.0295
	17:30	3.5020	3.5630	4.3681	3.6617	8.6286	7.9527
	18:30	5.6544	4.9496	5.7634	5.8550	8.1008	6.7178
	19:30	4.2529	5.2129	4.4103	5.3077	4.5885	4.0713
	20:30	2.3732	3.3152	2.5257	2.6171	3.9249	3.4719
	21:30	3.8850	2.4097	3.2139	2.4998	5.2268	5.6226
	22:30	4.6134	3.9260	4.7376	4.8078	5.7893	5.4179
	23:30	2.9289	4.6326	3.8290	4.6949	3.9617	2.8443

Virtual Environment 2013

Project File: After.mit
Sim File: low_glass_e_inside.aps 29/Sep/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: lower_sol_ab_roof.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: lower_e_roof.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: trans_lower.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: before.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw
Sim File: after.aps 29/Aug/2014
Weather File: SPtMasterTable_552779_9999_amy.epw

	Solar gain (MWh)	Solar gain (MWh)	Solar gain (MWh)	Solar gain (MWh)	Solar gain (MWh)	Solar gain (MWh)
	45 rooms	45 rooms	45 rooms	45 rooms	45 rooms	45 rooms
Date	**Low glass e inside aps**	**Lower sol ab roof aps**	**Lower e roof aps**	**Trans lower aps**	**Before aps**	**After aps**
Jan 01-31	1.2625	1.3679	1.3679	1.3679	3.6635	2.9811
Feb 01-28	1.3960	1.5138	1.5138	1.5138	4.2717	3.3177
Mar 01-31	1.5662	1.6920	1.6920	1.6920	4.6725	3.6413
Apr 01-30	1.6167	1.7473	1.7473	1.7473	4.6347	3.7567
May 01-31	1.7001	1.8370	1.8370	1.8370	4.5811	3.9543
Jun 01-30	1.7174	1.8561	1.8561	1.8561	4.5549	4.0155
Jul 01-31	1.7092	1.8455	1.8455	1.8455	4.5493	3.9519
Aug 01-31	1.6424	1.7717	1.7717	1.7717	4.6540	3.7503
Sep 01-30	1.5436	1.6666	1.6666	1.6666	4.6060	3.5556
Oct 01-31	1.6213	1.7467	1.7467	1.7467	4.8113	3.6846
Nov 01-30	1.2295	1.3301	1.3301	1.3301	3.5165	2.8613
Dec 01-31	1.0814	1.1675	1.1675	1.1675	2.9544	2.4766
Summed total	18.0863	19.5420	19.5420	19.5420	51.4697	41.9468

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TRAINING CERTIFICATE

This is to certify that

Ali El Bakkuhs

of **Herriot-Watt University**

attended and completed face-to-face training

in the following **Virtual Environment** software:

IES VE Product	Date Attended
ModelIT, SunCast	**26th February 2014**
ApacheSim,MacroFlo	**27th February 2014**
VE-SBEM, VE-DSM	**28th February 2014**

Integrated Environmental Solutions Ltd

Hans Dhargalkar
Training Manager

Appendixes 4-A Poster presented by the researcher

Improving Solar Gain Control Design Strategies in Residential Building Located in Hot Arid Areas

Ali Fathi El Bakkush*
Douglas J Harris**

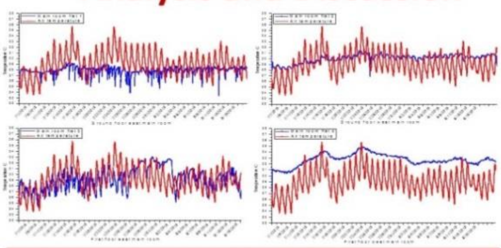
Overview

This research investigates the thermal performance of the building using the inside and outside temperature, and the on/off state of the air conditioner. This is significant because recently-built residential buildings in Libya provide a poor quality indoor environment and require a huge amount of energy to run the air conditioning.

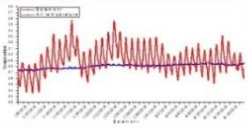
Objectives

- To investigate indoor and outdoor temperatures and energy consumption.
- To develop guidelines for solar control devices and strategies for residential building in hot arid climates to enhance comfort conditions.
- To provide the guidance needed by building designers in selecting the most appropriate tool for designing solar control devices.

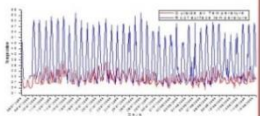
Analysis and Discussion

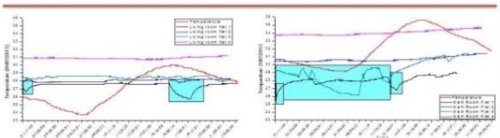


Basement temperature Is not affected much by the outside temperature.

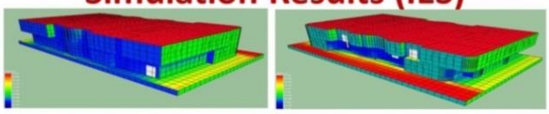


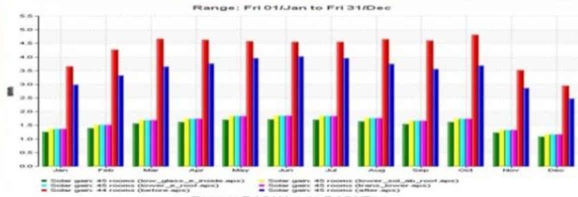
The roof absorbs the solar heat and in the middle of the day the surface can reach up to 65°C, the difference between the day and night temperature up to 30°C.

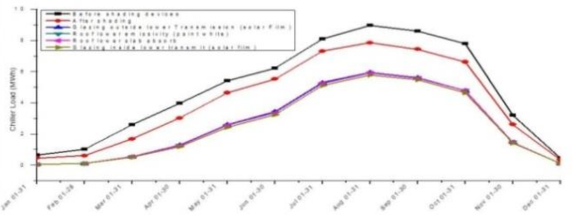




Simulation Results (IES)







Conclusion

- Roof surface is the most significant heat absorber in the building.
- whenever the outside temperature increase the electricity consumption of the building increases.
- Flats located in ground floor use the conditioner during the day while flats in first floor use it more at night due to heat transfer (Time lag).
- It is clear that the basement temperature is not affected by the outside temperature.

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This certificate is awarded to

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for his poster presentation entitled "*Improving solar gain control design strategies in residential buildings located in hot arid areas*".

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Appendixes 4-B Conference paper presented by the researcher

The 7th International Conference of SuDBE2015, Reading, UK; 27-29 July, 2015

Topic: T2.3 Performance Evaluation Reference number: 2033

Thermal Performance Measurements of a Residential Building Located in Hot Arid Area (Tripoli-Libya)

Ali Fathi M El Bakkush*, and Douglas J Harris

School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University, Edinburgh EH14 4AS, UK

Abstract: A large number of recently-built residential buildings in Libya provide a poor quality indoor environment or require a huge amount of energy to run the air conditioning, therefore influencing the thermal comfort, energy consumption and carbon emissions. As the use of energy in buildings is the major contributor to air pollution and global climate change, improving energy efficiency through the application of bioclimatic design principles in residential buildings in Libya is a critical factor in reducing energy consumption, securing thermal comfort, and hence is an effective policy for reducing the environmental impacts such a global warming and ozone layer depletion. A domestic building in Libya was studied with a view to reducing its energy consumption. The study included detailed monitoring, followed by computer simulation of a range of intervention strategies. The use of appropriate orientation, materials and building configuration would offer suitable solutions for energy and environmental problems in hot arid countries. This hypothesis is to be examined through an example located in Libya.

Key words: Building Energy; Architectural design; Energy saving in building; Overheating.

1 Introduction

Tripoli city lies on the far north of the continent of Africa overlooking the Mediterranean Sea. The ordinates of the city are latitude 32^{o} 47” N and longitude 13o 04” E respectively. Tripoli is classified as a hot dry climate, this type of climate usually being found at latitudes between 20°C and 35°C, and the main shelter issue is overheating. The mean summer temperatures are around 25^{o}C but can reach a maximum of 45^{o}C; clear nocturnal skies can cool temperatures down as -10°C. Furthermore, the building studied is located in the city of Tripoli, where summertime air temperatures can reach as high as 46^{o}C. Energy consumption in the residential sector in Libya is approximately 36% of the total; most of this is used for cooling buildings. Electricity generation increased by 50% between 2000 and 2010 (GECOL, 2013). Although Libya is an oil producing country, there is an energy crisis in Libya due to; extensive use of conventional energy sources leading to their depletion; the increase in the individual annual consumption of electrical energy; most of the energy consumption being from non-renewable sources; inefficiency of electricity generation.

2 Experimental Work

A field study including temperature, humidity and electricity consumption measurements was carried out and results from the study were gathered and analyzed. Moreover a computer simulation model was built using IES software, a fully dynamic simulation model to investigate the potential influence of changes to the building. The simulation was validated via comparison between the field measurements and the simulation results for the hot period.

The case study residential building has a rectangular plan and was built in 1999. The building is two stores high with a total height of 8 m. The ceiling height is 3.5 m. The ground floor is 1m above street level and the roof has a sill of one meter.

All the building construction is concrete, where all the internal and external walls are concrete blocks with dimension of 20cm thick, 20cm height, and 40cm wide, Covered from about side with 1-2cm mortar, more over the roof was built of reinforced concrete with 45cm thickness in the middle of the building and 25cm from the edge of the roof.

The floor area is approximately 700 m^2 for the first floor; this includes two flats, each of which has two bedrooms, two living rooms, two bathrooms, and a kitchen. The second floor is also divided into two flats, each of these having three bedrooms, two living rooms, a kitchen and three bathrooms. It is occupied as a multifamily residence. The building was monitored continuously for 45 days, and the results clearly showed that there were two peak days; in between these days there is a sharp drop in temperature, otherwise the average temperature range is between 27°C-33°C. Two typical days were selected for detailed study, the first being the peak day (21/07/2013), the second day having a low temperature (09/07/2013). The outside air temperatures for the three days are shown in figure 1.

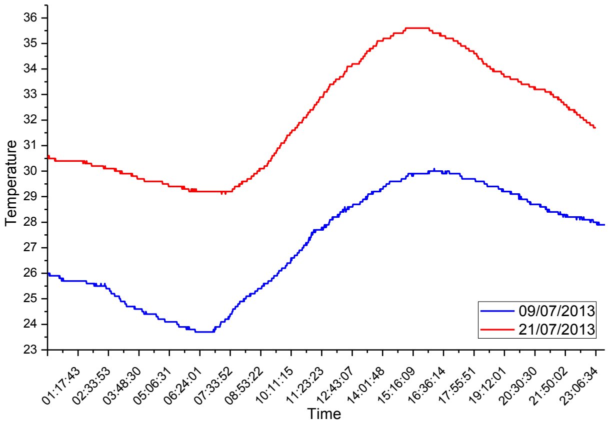

Fig.1 Outdoor air temperatures for the tow days

3 Results and discussion

3.1. Internal results

From the huge data that was gathered from the site, and for the limitation of the paper two rooms were focused on, the main room and the living room on both east and west sides. Figure 8 shows that both main rooms and living rooms on the 9th of July were stable until 15:00 when the temperature outdoors reached the peak of 30°C, in the main room and living room on the east façade the air-conditioning was turned on to cool down the temperature, while the west rooms continue stable for the rest of the day. The other interesting part is that the energy consumption follows the outdoor air temperature, which indicates that more air-conditioning is used when the temperature is rising as shown in figure 2.

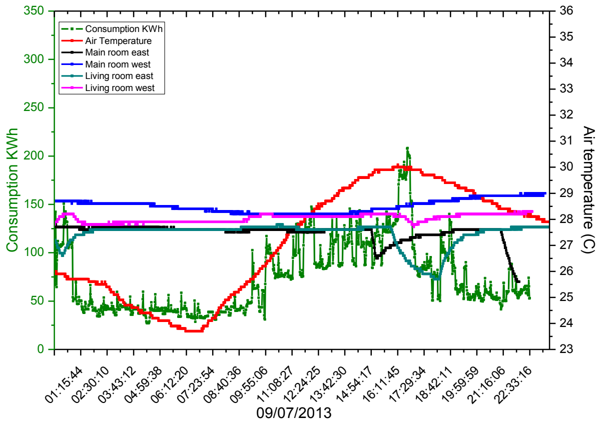

Fig.2 Temperatures for the east and west façade on the 9th of July

On the 21st of July the east façade was stable with temperature of 28.5°C until midday, after which both main room and living room used air conditioning to cool the space as the outdoor air temperature continued to rise to reach a peak of 35.5°C at 17:00; on the other hand the west façade main room is constant at around 31°C, while the living room is around 28°C. Furthermore, the energy consumption was almost steady at about 100kWh until 12:00, a few hours later rising to 350kWh due to 7°C difference in outdoor temperature. At 17:00 the temperature starts to fall although the energy consumption does too as shown in figure 3.

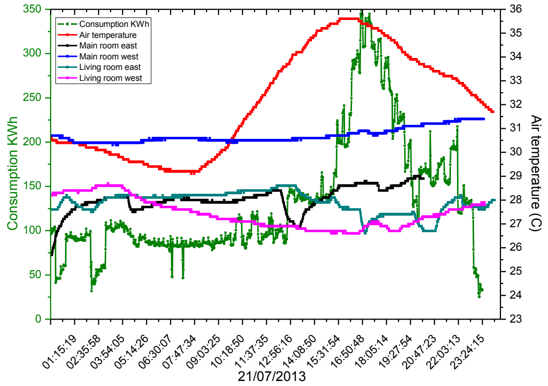

Fig.3 Temperatures for the east and west façade on the 21st of July

3.2. External results

For the façade temperature on the 9th of July as shown in figure 4 all facades are steady around 25°C until sunrise at 06:00 for the east and north façade while the rest of the façade until 08:00 starts to rise with the air temperature. Sun rays starts to hit east façade to reach the peak of 43°C at 10:00 than start to cool down due to the sun position, the while west façade at 12:00 starts to rise until 18:00 with temperature of 46°C. Furthermore, the roof surface temperature rises from sunrise to sunset as it absorbs the heat and reaches a high of 62°C at 14:00.

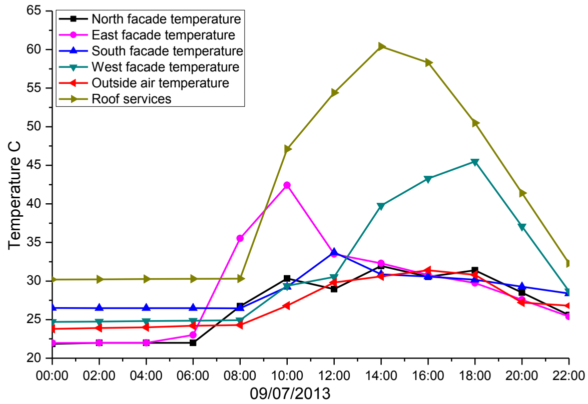

Fig.4 Façade temperatures on the 9th of July

For the 21st of July there is no difference in the pattern, the only difference being that the temperatures all days are following the same trend, the east façade temperature rises up from early morning until 10:00 when it reach the highest point, on the other hand the west façade start to rise at 10:00 until 18:00 it can reach up to 63°C. The major problem is the roof where it absorbs all the heat all day and transfers it to inside the building it is clearly shown in figure 5.

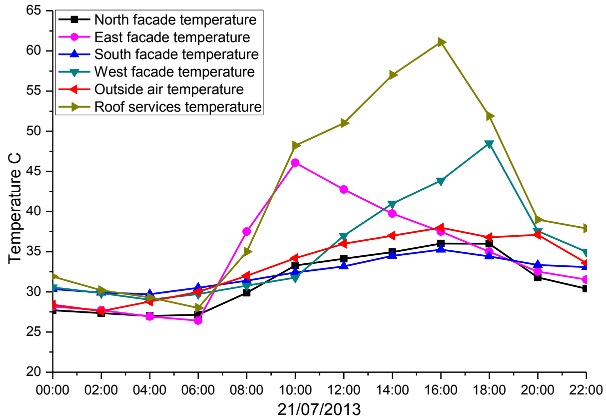

Fig.5 Façade temperatures on the 21st of July

4 Conclusions

After an extensive study on the building in the current conditions, and from the all measurements made on the building internal and external, it is clearly identified that the building absorbs heat from different aspects at different times of day, the east façade absorbing heat early in the morning and the west façade absorbing it in the afternoon, while the roof absorbs the heat all day, so that rooms located on the east side will warm up earlier than west side, and depending on the time lag that the heat will transfer from the outer surface to the inner one.

In this case there is number of changes must be made to cut down the building heat absorption which will also cut done the energy consumption. Because it is an existing building the range of options is limited and whatever is going to be done will be far more expensive than if it is done from the beginning of the design stage. The five main improvements that can be made at this stage are:

- Adding shading to the building especially on the east and west façade.
- Placing external solar film glazing with lower transmission.
- Painting the roof with white lower emissivity painting.
- Adding to the roof lower slab absorber.
- Placing internal solar film glazing with lower transmission.

The building has been modelled by IES software as it is, with no any changes, and compared with the same with added shading devices on both east and west facades, placing external and internal solar film glazing with low transmission, painting the roof with white lower emissivity painting, and adding insulation to the roof lower slab absorber. Figure 6 shows the run simulation results for the building solar gain monthly for the whole year.

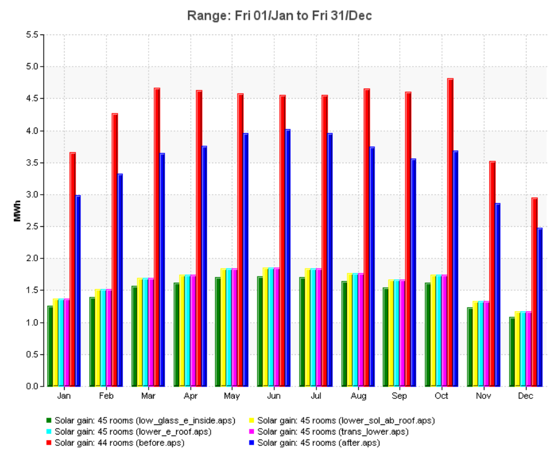

Fig.5 Simulation results for the building solar gain

Table 1 shows the figures as each additional measure was carried out, for the building as it is it shows that it absorbs

51.4697 MW/h solar gains presumably this is the 100% gain. The results showed that 18.5% can be cut down by just adding the shading devices on east and west side, while the impressive result is by adding external solar film on the glazing which can cut 62% from the solar gain, moreover, painting the roof with white paint and adding slab absorber to it did not change the result, while adding internal solar film on the glazing can cut extra 3% to be in total 65%.

Table 1 Solar gain figures for each additional adding on the building

Solar Gain (MWh)						
Date	**Before shading devices**	**After shading**	**Glazing outside lower Transmission (solar Film)**	**Roof lower emissivity (paint white)**	**Roof lower slab absorb**	**Glazing inside lower transmit (solar film)**
Jan 01-31	3.6635	2.9811	1.3679	1.3679	1.3679	1.2625
Feb 01-28	4.2717	3.3177	1.5138	1.5138	1.5138	1.3960
Mar 01-31	4.6725	3.6413	1.6920	1.6920	1.6920	1.5662
Apr 01-30	4.6347	3.7567	1.7473	1.7473	1.7473	1.6167
May 01-31	4.5811	3.9543	1.8370	1.8370	1.8370	1.7001
Jun 01-30	4.5549	4.0155	1.8561	1.8561	1.8561	1.7174
Jul 01-31	4.5493	3.9519	1.8455	1.8455	1.8455	1.7092
Aug 01-31	4.6540	3.7503	1.7717	1.7717	1.7717	1.6424
Sep 01-30	4.6060	3.5556	1.6666	1.6666	1.6666	1.5436
Oct 01-31	4.8113	3.6846	1.7467	1.7467	1.7467	1.6213
Nov 01-30	3.5165	2.8613	1.3301	1.3301	1.3301	1.2295
Dec 01-31	2.9544	2.4766	1.1675	1.1675	1.1675	1.0814
Total	51.4697	41.9468	19.5420	19.5420	19.5420	18.0863
%	100%	-18.5%	-62.00%	-62.00%	-62.00%	-64.86%

To make it more clear figure 6 shows this in different way just to understand the huge difference that can be made to cut down the solar gain.

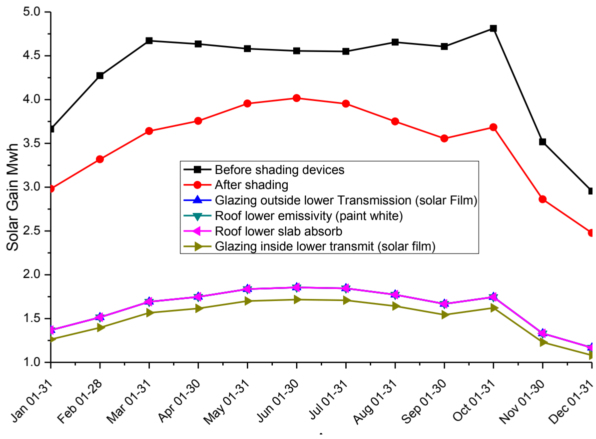

Fig.6 Building solar gain by each month

One of the biggest energy users is the air conditions - figure 7 shows how the changes can affect the chiller loads which will lead to savings in energy consumption of varying degrees, according to the change and modification.

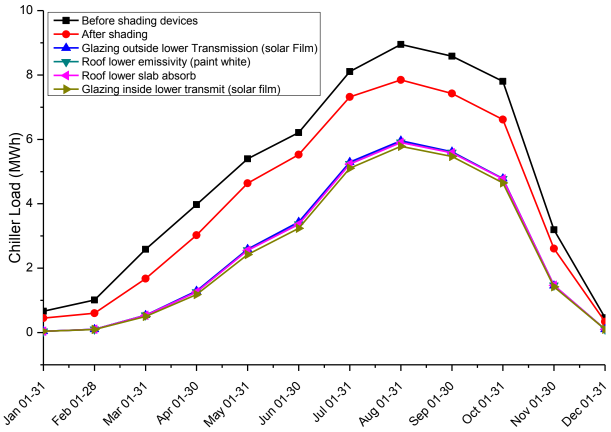

Fig.7 Building chiller load by MWh

Table 2 shows the total chiller loads for each month during the year, indicating that the building uses 56.94MW/h at the time being, while if shading devices are added it can cut 15.78% from the total chiller load, and for the most impressive saving is to add outside solar film on the glazing witch can save 45.18%. Furthermore, adding to the roof lower emissivity paint and slab absorber will not add extra saving (not more than 1%), while 2% more can be saved by adding internal solar film on glazing, however this is not worthwhile for the impact as it will reduce the natural light to the building.

Table 2 Chiller load figures for each additional adding on the building

Chiller Load (MWh)						
Date	**Before shading devices**	**After shading**	**Glazing outside lower Transmission (solar Film)**	**Roof lower emissivity (paint white)**	**Roof lower slab absorb**	**Glazing inside lower transmit (solar film)**
Jan 01-31	**0.6647**	**0.4506**	**0.0379**	**0.0379**	**0.0379**	**0.0379**
Feb 01-28	**1.0130**	**0.6003**	**0.1039**	**0.1039**	**0.1039**	**0.0939**
Mar 01-31	**2.5839**	**1.6763**	**0.5394**	**0.5423**	**0.5359**	**0.5004**
Apr 01-30	**3.9747**	**3.0220**	**1.2925**	**1.2620**	**1.2608**	**1.1799**
May 01-31	**5.3953**	**4.6359**	**2.5902**	**2.5644**	**2.5526**	**2.4252**
Jun 01-30	**6.2117**	**5.5248**	**3.4344**	**3.3687**	**3.3590**	**3.2363**
Jul 01-31	**8.1078**	**7.3182**	**5.2971**	**5.2414**	**5.2319**	**5.1029**
Aug 01-31	**8.9501**	**7.8493**	**5.9582**	**5.9058**	**5.9002**	**5.7843**
Sep 01-30	**8.5826**	**7.4236**	**5.6161**	**5.5920**	**5.5812**	**5.4678**
Oct 01-31	**7.8018**	**6.6190**	**4.7862**	**4.7794**	**4.7714**	**4.6475**
Nov 01-30	**3.1922**	**2.6099**	**1.4557**	**1.4692**	**1.4666**	**1.4229**
Dec 01-31	**0.4602**	**0.3398**	**0.1044**	**0.1044**	**0.1044**	**0.1004**
Total	**56.9381**	**48.0697**	**31.2159**	**30.9714**	**30.9058**	**29.9993**
%	**100%**	**-15.78%**	**-45.18%**	**-45.60%**	**-45.72%**	**-47.31%**

The most important part for the global impact is how much can we save in producing CO_2. Figure 8 clearly indicates how much the changes can save in CO_2 by Kg each month for the whole year, and it is clear that summer time is the peak CO_2 producer because the building use air conditioning more than the rest of the year, the higher the outdoor temperature increases the more CO_2 is produced.

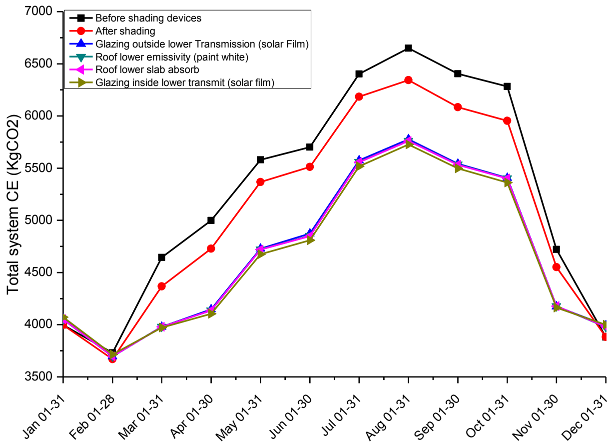

Figure 8 The total CO2 produced by the building

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Appendixes 4-C Journal papers presented by the researcher

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The Application of Building Modifications and their Effects on Energy Consumption in Buildings

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Abstract

A huge amount of energy is used for air-conditioning in residential buildings in hot climates. Passive design features such as shading and advanced glazing can help to reduce energy use and carbon emissions, and thus mitigate the impact on climate change. This paper aimed at demonstrating how the application of selected modification devices such as solar films and shading devices affects the energy consumption patterns and levels in a residential building. A model of a building was constructed with VE using "Model IT" module, which was then analysed in a variety of different ways. A Virtual Integrated Environmental Solutions (IES-VE) was used to assess the energy gain and consumption parameters such as solar gains, shading devices, solar cloud and chilli clouds in residential buildings in Tripoli, Libya. The findings indicate that the best way to control and reduce the energy gains pattern in a building is to introduce energy modification devices such as shading device, solar films, emissivity paints and roof slab absorbers among others. In specific terms, the best device would be the application of external solar film, follow by shading device and internal solar film. An application of emissivity paints and roof slab absorbers does not contribute significantly to the energy reduction in the building. The study concludes that the application of modification devices in buildings can reduces the heat gain significantly. This study underscores the need and importance of the applications of energy modification devices in buildings in order to reduce their energy gains in the context of tropical regions. Though the climatological characteristics of tropical regions are similar, the generalisation of the findings in this study requires caution since the findings are limited in geographical context. Future research should also explore the impact of urban forms, street layout and orientation on solar penetration and energy use in buildings.

Keywords: Architecture, Buildings, Climate change, Energy consumption, Energy gains, Libya

1. Introduction

The issue of energy gains and use in buildings in the built environment are teething issues which has gained a wider global attention (*cf.* Santamouris *et. al.,* 2001; Torcellini *et.al.,* 2006; Rijal *et. al.,* 2007; du Can and Price, 2008). In the tropical regions such as Tripoli in Libya, there is a growing concern about energy use in buildings and its likely adverse effect on the environment ((Ealiwa *et.al.,* 2001; El-Osta and Kalifa, 2003; Chowdhury *et.al.,* 2008). Although Libya has a lot of indigenous fuels of her own and need not rely on imported fossil fuels such as coal, natural gas and oil products, the increase in economic growth has been marked with an increase in energy consumption. Buildings, in addition to offering shelter and fulfilling aesthetic requirements, should provide conditions of comfort for their occupants. During summer, especially in hot climate, buildings are exposed to high intensities of solar gain, which may result in over-heating, causing discomfort to users. Under such conditions, energy conservation in the building is very important. The energy conservation processes can include diverse measures from simple natural cooling techniques, evaporative cooling and natural ventilation, to mechanical cooling systems (Santamouris and Asimakopoulos, 1996). Natural energy conservation systems which involved natural methods such as breezes flowing through windows, water evaporating from trees and fountains, as well as large amounts of stone and earth absorbing daytime heat are well known methods used particularly in developing countries. These ideas were developed over thousands of years as an integral part of all building designs and are known by many (*cf.* Givoni, 1991; Santamouris and Asimakopoulos, 1996; Breesch *et. al.,* 2005; Hatamipour and Abedi, 2008) as "passive cooling". These researchers further argue that by engaging passive cooling techniques in new buildings, the designer can often eliminate the need for mechanical cooling or at least reduce the size and cost of the cooling equipment and therefore reduce the overall cost of the cooling and energy conservation bill.

Despite these cost effective natural systems of energy conservations as suggested earlier by (Watson, 1979; Fathy, 1986), modern building designers often use a wide range of technologies to reduce the amount of energy that buildings need for cooling and energy conservation (Florides *et.al.,* 2002; Hughes *et.al.,* 2011). These modern technologies includes the application of shading device, external solar film, internal solar film, emissivity paints, roof slab absorbers among others. In the case of Tripoli during the summer, various sources of heat gain have to be dealt with, which includes direct solar radiation from outside, ventilation, and internal heat gains from inside the building such as lighting and other equipment. The estimation of the energy gains and consumption of buildings has received significant attention in the past few years, with the dual goal of reducing energy cost (cost concerns), and reducing the amount of greenhouse gases released in the atmosphere (environmental concerns). However, there is also limited research into how these heat or energy gains could be minimise to make occupants not only comfortable but less costly to them. Several methods and tools can be used to evaluate the energy gains and consumption in buildings, ranging from simple spreadsheets to full computer simulation programs. Also, there is still limited research in the context of Libya about the solar gains on an existing building.

2. Building Energy Conservation Strategies in Architecture

The issue of energy conservation is important in architecture simple because it is the greater consumer of the energy used throughout the world (Li and Colombier, 2009; Dixit *et. al.,* 2010). In the most advanced countries, from 35% to 40% of the total overall main use of energy is spent in buildings, a figure which approaches 50% when taking into account the energy costs of building materials and the infrastructure to serve building (Aitken, 2003). Buildings have traditionally been seen as energy and resource consumer. However, a new view is emerging in which newly designed buildings aim at making them a net contributor to the energy supply system by dropping their energy demand and act as energy supply source (Pitts, 2008). Langston, (2012) suggests that the main energy used in buildings is for heating, cooling and lighting. Meanwhile, Jarmul, (1980) suggests earlier that one major challenge facing designers and users of buildings is how to contain or prevent both heat lose and gains through the building envelope. This is especially during winter and summer periods. The energy consumption pattern in building are affected by so many factors and variables such as its design, the environment in which it is located and the way in which it is being use and operated.

In order to achieve the heating, cooling and lighting goals of buildings, there are three require perspectives that come into consideration. These are architectural design, natural energy, and mechanical equipment requirement perspectives. The architectural design perspectives of the building are concern with the minimization of heat loss during winter, heat gain in the summer and the use of light efficiently throughout the life span of the building. Any poor or unprofessional design decisions taken at this stage can easily double or triple the cost and the size of mechanical equipment requirement in particular and the energy requirement and usage in the building. The second perspective involves the use of natural energy conservation methods such as passive heating, cooling, and daylighting systems. A good decision at this point can greatly reduce the unresolved problems arising from the architectural design perspectives. The mechanical equipment requirement perspectives are achieved through the adaptation of non-renewable energy sources to handle the loads that remain after the two perspectives described above to reduce the loads as much as possible (Pehnt, 2006)

There are so many main sources of factors influencing the energy use in buildings in the built environment. These are factors arising from the building services, building envelope, the climate and human factors as showed in figure 1. Whiles the building envelope is influenced by factors such as location, orientation, size, built form, shape/layout, the building services are influenced by the type and size of systems, type of energy need and supply, plant efficiency, plant control, operating regime among others. Human factors include comfort requirements, occupancy regime, human activities, management and maintenance. The energy used in building is central to any strategy adopted to conserve the energy supply and demand with the aim of contributing to the current effort of reducing global warming. Many have therefore suggested that, the impacts of buildings upon the energy consumption and global warming comes in four separate folds. These are the production of materials and products used in constructing the building, the fabrication and construction process, the heating, cooling, ventilation, and lighting of the buildings in use (Edwards, 1995). The most important drivers of growth in energy gains and consumption in buildings are population growth (which effects on total consumption) poor residential building design increased interest of energy appliances in households to improve amenity (Price *et .al.,* 1998; Roth *et.al.,* 2002). Such practices are very prevalence in Libya.

2.1 The Building as an Energy System

A building can be describe in several ways including its being a concrete blocks insulation with windows, heating, cooling and ventilation systems. Its energy system requirement must consider the social interactions between the occupants, environment and the building. The activities that take place in and outside the building either generate or gain heat through so many ways. For instance, (Liu and Harris, 2013) suggests that heat transfer particularly convective heat is influence by the temperature, the speed and direction of the wind of the building surroundings. The influential factors influencing the thermal performance of a building are as shown in figure 2. These factors inevitably need careful considerations during the design, construction and maintenance period of the building.

2.2 The Energy consumption pattern in Libya

Libya's consumption of electrical energy in particular is distributed into four major sectors: the industrial sector, the agricultural sector and the residential and commercial sectors as shown in figure 3. Close to 40% of the total primary energy in Libya is used in power generation and almost 100% of the fuel used to generate power is from fossil fuel and 0% renewables (GECOL, 2013). It is well recognized from the above figures that residential and industrial buildings account for a large percentage of all delivered energy consumption in the country. Although Libya is an oil producing country, there is an energy crisis in Libya for many reasons that include extensive use of conventional energy sources which are leading to their depletion, and the increase in the individual annual consumption of electrical energy. Again, most of the energy consumption is of non-renewable sources while the use of renewable sources is still in the foundation stages. There is inefficiency in electricity generation, which could lead to depletion of oil reserves in the near future. The total CO_2 emissions in Libya are around 60 million tonnes CO_2 per year (55% due to oil and 45% due to Natural gases) (GECOL, 2013) as shown in figure 4.

2.3 Climatological analysis of the city of Tripoli

The city of Tripoli lies on the far north of the continent of Africa overlooking the Mediterranean Sea. The ordinates of the city are within latitude 32^o 47" N and longitude 13^o 04" E respectively. The city is classified as a hot dry climate usually being found around latitudes 20° and 35°. The main shelter challenges facing inhabitant in such regions is overheating. The mean summer temperatures are around 25^{o}C but can reach a maximum of 45^{o}C. However, clear nocturnal skies sometimes cool the temperatures down to as low as -10°C. The building studied is located in the city of Tripoli, which incidentally is only 21Km north of the area where the hottest air temperature ever recoded of 58°C (Hocine and Sharples, 2010). Table 1 show the yearly temperature condition readings for the average minimum and average maximum daily temperatures of the city where the building is located.

2.4 The effects of solar gains, chiller clouds and CO_2 on the building

In a tropical region such as Tripoli, the indoor comfort depends largely on so many factors such as air temperature, air humidity and air movement. The convective heat removed makes up the sensible cooling load, and the excess water vapour removed constitutes the latent cooling load. The cooling load of the space within a building according to (Zain-Ahmed *et. al.,* 2002.p.1725) is *the heat that must be removed by mechanical means to maintain the space at the desired conditions.* They further argue that whiles the external heat gains in building consist of the solar radiation conducted through the opaque building materials and transparent openings, the internal heat loads are caused by the occupants, artificial lighting and mechanical and electrical equipment.

The importance and paybacks on light roof colour has gain the attention of many especially in areas where the sun is right overhead single story buildings (Eilert, 2000). Also, Parker *et.al.,* (1996) Parker *et.al.,* (1997) demonstrates in a study of Florida homes in which after the application of a reflective roof coatings the space cooling requirements decreased by 19% and the interior comfort was also improved after the grey bitumen roof surface was painted white. In another study (Suehrcke, 2001) also demonstrate with the use of numerical simulation that the peak values of heat flow from a roof could be reduce by as much as 60% when a white surface replaces a corroded galvanised one. It has been argue that the thermal performance of a building is affected by the solar absorptance of the roof and other parts of the building. Suehrcke *et.al.,* (2008.p.2224) supports this argument that *during clear sky conditions up to about 1 kW/m^2 of solar radiation can be incident on a roof surface, and between 20% and 95% of this radiation is typically absorbed*. Black surface with low visible reflectance often suggests a high solar absorptance and this indicates that the colour of roof gives an indication of the value of solar absorption in buildings. The above studies attest to the fact that heat flow from roof can be significantly reduces by the application of modification devices.

The issue of carbon dioxide (CO2) emission has become a major concerned for researchers and policy makers in both developed and developing countries all over the world. It is reported that in 2004, the total emissions of CO_2 from residential and commercial buildings were 2236 million metric tons which was more than either the transportation or industrial sectors in USA (USGBC, 2008; Hartgen *et.al.,* 2011). It is again projected that in the next 25 years, CO_2 emissions from grow faster than any other sector, with emissions from commercial buildings projected to grow the fastest. Modern technology has made it possible for the easy quantification of the amount of CO_2 as a *gauge* to enable and ensure ventilation systems are design and delivered to the recommended minimum quantities of outside air to the building's occupants (Prill, 2000).

3. Methodology

The paper adopted computer simulation software that was validated via comparison between the field measurements and the simulation results for the hot period. The calibration model shows that the difference between them was less than 1°C. Virtual Environment by Integrated Environmental Solutions (IES-VE) is a modern example of dynamic building energy simulation software which was used for the simulation. IES-VE consists of a suite of integrated analysis tools, which can be used to investigate the performance of a building either retrospectively or during the design stages of a construction project figure 6. IES enables the specific understanding of the site to automatically outline suitable bioclimatic architecture strategies for the project; such as pre-design sustainability direction among others. The selected building was a renovated project which enables IES-VE to identify the best passive solutions, comparing low-carbon technologies, and drawing conclusions on energy use, CO_2 emissions, occupant comfort, light levels, and much more. IES-VE for engineers also allows easily visualising and communicating results at a highly detailed level. A carefully and cautiously building details and materials where used in the construction of the building where input to the IES software for the dimensions of windows, openings, which were all incorporated in the program as shown in figure 7.

Calculations were done for the position of the sun in the sky, tracks solar penetration throughout the building interior and shadows were all done. Using a central simulation process enables the user to assess every aspect of the thermal performance as well as share results and input across a wide variety of other VE engineering modules. The building was modelled by IES software as far as possible exactly as it was on the site with no major changes, except those inevitably required by the conditions of modelling. Once the base model was simulated and validated, modifications to the building were simulated through four steps. The first step involves the provision and application of shading device on both sides of the east and west elevations of the building. This was followed by placing an external and internal solar film on the glazing with low transmission ones. Thirdly the roof was painted with white lower emissivity paints and finally a concrete roof slab insulation absorber was added to the roof slab. Figure 9 show the building after the addition of 700 x 700 x 100mm thickness horizontal and vertical shading devices.

4. Discussions of the simulation results

4.1 Solar gain result

Figure 10 show the south, east, north, west and roof simulation results for the outer surface solar gain in KWh/m^2. The east façade was in the average of $3.81KWh/m^2$, while the ground floor on the south façade was less than the first floor with $1.25KWh/m^2$ compared to the first floor with $2.28KWh/m^2$. The roof is the biggest absorber of heat gain in the building with figures above $7.61KWh/m^2$. The North façade has the lowest heat absorption among all the elevations with less than $0.76KWh/m^2$, and the west façade had almost the same as the east façade with $3.81KWh/m^2$. After simulating the building to ascertain the solar gains for the whole year and comparing the figures with the modification simulation figures as depicted in table 2. It shows that the building for the period of summer, solar gains was above 4.5MW/h. It's also shows the solar gains of 51.4697 MW/h presumably this is 100% into the building. However, after the additions of the modification mechanisms, the results shows that 18.5% of solar gain could be reduce by just adding a shading device on the eastern and western facades of the building. Also, the impressive results shows that by adding an external solar film to the glazing width can reduce the solar gains by 62%. Moreover, painting the roof with white colour paints and adding roof slab absorber could not change the results in any significant way. Additionally, an application of an internal solar film on the glazing also reduces the solar gains by extra 3% bringing the total solar gains reduction to about 65%. Table 1 depicts the simulation results for the solar gain figures for each additional modification device to the building. To make it more clear figure 11 shows a significant impact on reducing the solar gains of the various measures and modification mechanisms.

4.2 Chillers louds

One of the largest energy user units in a typical building is air-conditioning. Figure 12 shows how the changes can affect the chiller loads which could lead to savings on energy consumption of varying degrees according to the modifications made to the building. Table 2 shows the total chiller load for each month during the year, which indicates the building uses 56.94MW/h before the modification. However, after the addition of the shading devices, the chiller loads reduces by 15.8% of the total chiller load. Therefore, for the best savings to be achieved, an addition of an outside solar film on the glazing saves up to 45.2% of the total chiller loads. Furthermore, adding to the roof lower emissivity paints and slab absorber would add not more than 1% extra savings. While 2% more can be saved by adding internal solar film on glazing, this is probably not worth doing since the impact of natural lighting to the building could also offsets such gains.

4.3 CO2 produced by the building

From global viewpoint, the most important aspect or concern was to analyse how much the building under study could make some savings in the production of CO_2. Figure 13 clearly indicates how much savings of CO_2 in Kg each month that could be made on the building for the whole year. It is clear that summer times are the peak CO_2 production time simple because the building uses air-conditioning more than the rest of the year. The higher the temperature increase during such periods the more the production of CO_2 and this often results in a positive relationship. Table 4 shows the total amount of CO_2 in Kg for each month during the year. The results show that the building produced 62995Kg CO_2 yearly. However, after the addition of the shading devices, it became 60644Kg, indicating a reduction of 3.8% less than the total. It also reduces by 11.20% to become 55951Kg, after adding external solar film. Moreover, the rests shows that adding roof lower emissivity, roof lower slab absorber, and solar film inside the glazing could not change more than even 0.5%.

4.4 Chiller energy

Figure 14 shows the chiller energy for the whole year, illustrating that the greatest use of energy is in summer time, especially July to October. The energy consumption starts from March and increase gradually to reach the peak in August, and then retreats gradually until October and falls in November. In winter time it starts from December to February and chiller energy is almost non-existent or insignificant compared to the summer months. Chiller energy is one of the things that the study was able to reduce approximately by half of the total. Table 4 shows the simulation results for the whole year. Before the application of the devices, the building uses 22.78MWh/year and after the application of the shading devices it became 19.25MWh/year, representing a 15.6% reduction. Huge reduction was achieved after placing solar films on the lower transmission outside the glazing with 45.20% to 12.49MWh/year. For more reduction solar film can be placed inside the glazing and this could reduce it by extra 2%.

5. Conclusion

In order to measure the energy use in a building, the chiller energy use has often been used as the main benchmark. From the simulations results as compare with that of the unstimulated, the following conclusions could be made. It could be concluded that the best way to control, reduce the energy consumption pattern in a building is to introduce energy modification devices such as shading device, external solar film, internal solar film, emissivity paints, roof slab absorbers among others. In specific terms, the best device for reducing solar gains would be the application of external solar film, follow by shading device and internal solar film. An application of emissivity paints and roof slab absorbers would amount to waste of resources. Similarly for chiller louds reduction, the best device would still be the application of external solar film, follow by shading device and internal solar film. An application of emissivity paints and roof slab absorbers would still not add much and therefor would consider as waste of resources.

External solar film devices are again suitable mechanism for the reduction of CO2 in buildings. This is followed by shading device and the rest may not contribute and significant values in this regards. Surprisingly internal film device stand out to be the best device for chiller energy reduction in buildings. This is also followed by external solar film and shading device. The contribution of emissivity paints and roof slab absorbers are again insignificant. Finally and more importantly, the application of both external solar film and shading devices would together reduce the effects of energy consumption in buildings significantly. How, an addition of internal solar film device would complete in some cases particularly in the reduction of solar gains and chiller energy. Future research should also explore the impact of urban forms, street layout and orientation on solar penetration and energy use in buildings.

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Table 1: The simulation results for the building solar gain.

	Solar Gain (MWh)					
Date	**Before shading devices**	**After shading**	**Glazing outside lower Transmission (solar Film)**	**Roof lower emissivity (paint white)**	**Roof lower slab absorb**	**Glazing inside lower transmit (solar film)**
Jan 01-31	3.6635	2.9811	1.3679	1.3679	1.3679	1.2625
Feb 01-28	4.2717	3.3177	1.5138	1.5138	1.5138	1.3960
Mar 01-31	4.6725	3.6413	1.6920	1.6920	1.6920	1.5662
Apr 01-30	4.6347	3.7567	1.7473	1.7473	1.7473	1.6167
May 01-31	4.5811	3.9543	1.8370	1.8370	1.8370	1.7001
Jun 01-30	4.5549	4.0155	1.8561	1.8561	1.8561	1.7174
Jul 01-31	4.5493	3.9519	1.8455	1.8455	1.8455	1.7092
Aug 01-31	4.6540	3.7503	1.7717	1.7717	1.7717	1.6424
Sep 01-30	4.6060	3.5556	1.6666	1.6666	1.6666	1.5436
Oct 01-31	4.8113	3.6846	1.7467	1.7467	1.7467	1.6213
Nov 01-30	3.5165	2.8613	1.3301	1.3301	1.3301	1.2295
Dec 01-31	2.9544	2.4766	1.1675	1.1675	1.1675	1.0814
Total	**51.4697**	**41.9468**	**19.5420**	**19.5420**	**19.5420**	**18.0863**
%	**100%**	**-18.5%**	**-62.00%**	**-62.00%**	**-62.00%**	**-64.86%**

Table 2: Chiller load figures for each additional adding on the building.

	Chiller Load (MWh)					
Date	**Before shading devices**	**After shading**	**Glazing outside lower Transmission (solar Film)**	**Roof lower emissivity (paint white)**	**Roof lower slab absorb**	**Glazing inside lower transmit (solar film)**
Jan 01-31	0.6647	0.4506	0.0379	0.0379	0.0379	0.0379
Feb 01-28	1.0130	0.6003	0.1039	0.1039	0.1039	0.0939
Mar 01-31	2.5839	1.6763	0.5394	0.5423	0.5359	0.5004
Apr 01-30	3.9747	3.0220	1.2925	1.2620	1.2608	1.1799
May 01-31	5.3953	4.6359	2.5902	2.5644	2.5526	2.4252
Jun 01-30	6.2117	5.5248	3.4344	3.3687	3.3590	3.2363
Jul 01-31	8.1078	7.3182	5.2971	5.2414	5.2319	5.1029
Aug 01-31	8.9501	7.8493	5.9582	5.9058	5.9002	5.7843
Sep 01-30	8.5826	7.4236	5.6161	5.5920	5.5812	5.4678
Oct 01-31	7.8018	6.6190	4.7862	4.7794	4.7714	4.6475
Nov 01-30	3.1922	2.6099	1.4557	1.4692	1.4666	1.4229
Dec 01-31	0.4602	0.3398	0.1044	0.1044	0.1044	0.1004
Total	**56.9381**	**48.0697**	**31.2159**	**30.9714**	**30.9058**	**29.9993**
%	**100%**	**-15.6%%**	**-45.2%**	**-45.6%**	**-45.7%**	**-47.3%**

Table 3: CO2 figures for each additional modification devices to the building

	Total system CE (kgCO2)					
Date	Before shading devices	After shading	Glazing outside lower Transmission (solar Film)	Roof lower emissivity (paint white)	Roof lower slab absorb	Glazing inside lower transmit (solar film)
Jan 01-31	3997	3998	4058	4050	4052	4072

Feb 01-28	3731	3670	3697	3696	3697	3714
Mar 01-31	4645	4367	3980	3981	3979	3972
Apr 01-30	4999	4728	4148	4136	4136	4104
May 01-31	5580	5368	4729	4722	4719	4675
Jun 01-30	5701	5512	4873	4852	4849	4810
Jul 01-31	6403	6184	5575	5561	5557	5517
Aug 01-31	6649	6344	5776	5762	5761	5726
Sep 01-30	6405	6085	5543	5536	5532	5497
Oct 01-31	6282	5954	5406	5403	5401	5361
Nov 01-30	4721	4552	4174	4178	4177	4164
Dec 01-31	3881	3882	3993	3978	3981	3999
Total	**62995**	**60644**	**55951**	**55856**	**55842**	**55611**
%	**100%**	**-3.8%**	**-11.2%**	**-11.3%**	**-11.4%**	**-11.7%**

Table 4: Shows chiller energy simulation results

Chiller Energy (MWh)						
Date	Before shading devices	After shading	Glazing outside lower Transmission (solar Film)	Roof lower emissivity (paint white)	Roof lower slab absorb	Glazing inside lower transmit (solar film)
Jan 01-31	0.2659	0.1802	0.0152	0.0152	0.0152	0.0152
Feb 01-28	0.4052	0.2401	0.0416	0.0416	0.0416	0.0375
Mar 01-31	1.0336	0.6705	0.2158	0.2169	0.2143	0.2002
Apr 01-30	1.5899	1.2088	0.5170	0.5048	0.5043	0.4719
May 01-31	2.1581	1.8544	1.0361	1.0257	1.0210	0.9701
Jun 01-30	2.4847	2.2099	1.3738	1.3475	1.3436	1.2945
Jul 01-31	3.2431	2.9273	2.1188	2.0966	2.0928	2.0411
Aug 01-31	3.5801	3.1397	2.3833	2.3623	2.3601	2.3137
Sep 01-30	3.4330	2.9694	2.2465	2.2368	2.2325	2.1871
Oct 01-31	3.1207	2.6476	1.9145	1.9118	1.9086	1.8590
Nov 01-30	1.2769	1.0440	0.5823	0.5877	0.5866	0.5692
Dec 01-31	0.1841	0.1359	0.0418	0.0418	0.0418	0.0402
Total	22.7753	19.2279	12.4864	12.3886	12.3623	11.9997
%	100%	-15.6%	-45.2%	-45.6%	-54.8%	-47.3%

Table 5: Summary of the results after application of the modification devices

Modification devices Before	**Solar gains reduction**	**Chiller louds reduction**	**CO_2 reduction**	**Chiller energy**
	51.47MW/h	56.94MW/h	62995Kg	22.78MW/h
Shading device	18.50%	15.80%	3.80%	15.60%
External solar film	62.00%	45.20%	11.20%	45.20%
Internal solar film	3.00%	2.00%	0.50%	47.30%
Emissivity paints	0.00%	1.00%	0.50%	0.00%
Roof slab absorber	0.00%	1.00%	0.50%	0.00%

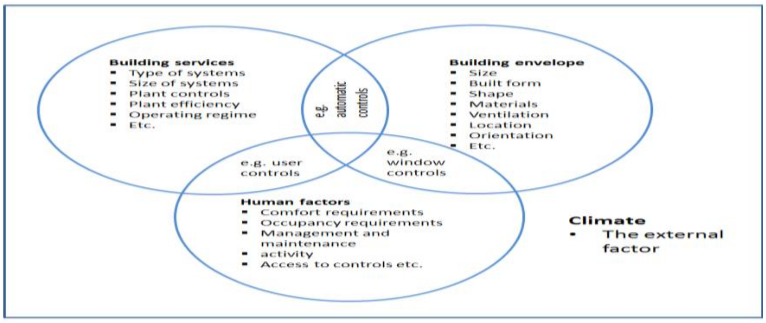

Figure 1: Key factors influencing energy use in buildings

Figure 2: Different aspects and their effect on the energy need of a building

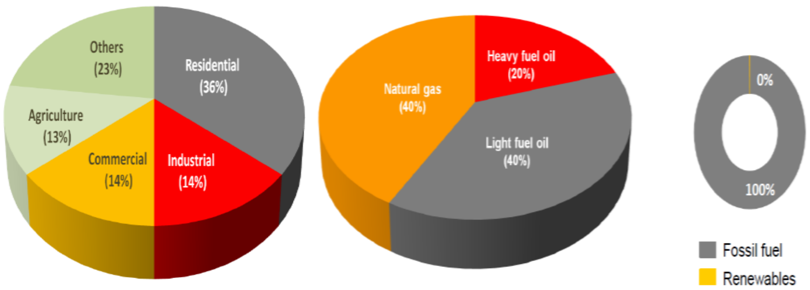

Figure 3: Electricity consumption per sector and by fuel type in Libya, Source: GECOL, (2013)

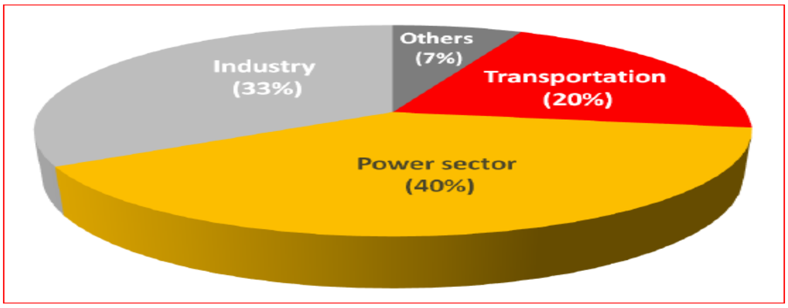

Figure 4: CO_2 emissions in Libya, Source: (GECOL, 2013)

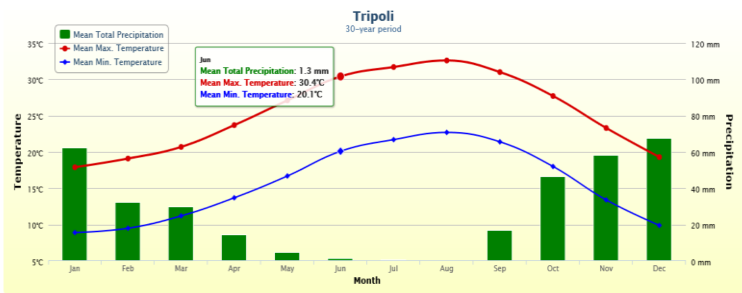

Figure 5: Ambient temperature in Tripoli, Source: World Meteorological Organization, (2014)

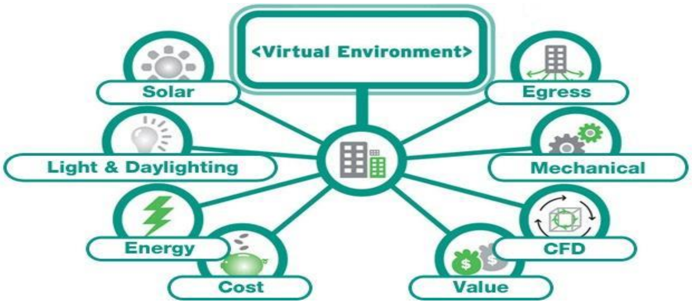

Figure 6: How the IES program works

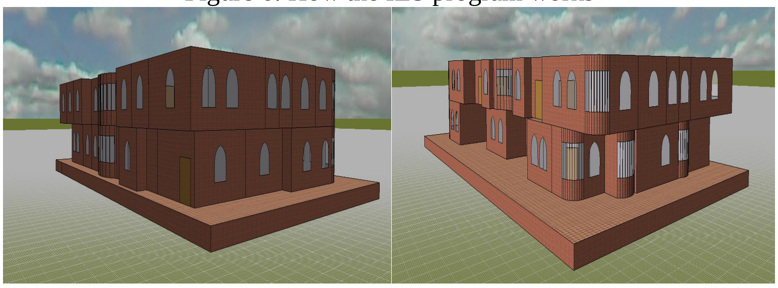

Figure 7: South and east and north and west elevations of the building after modelling it with IE

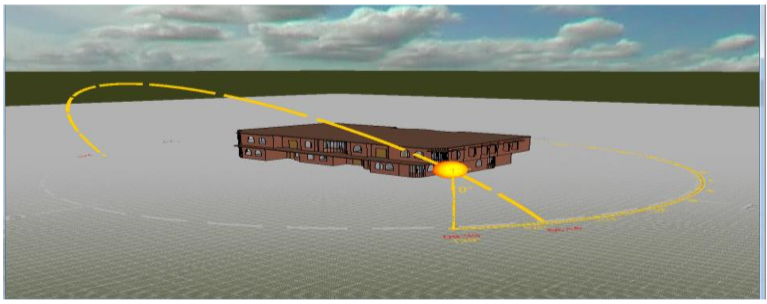

Figure 8: The building while the sun cast is calculated

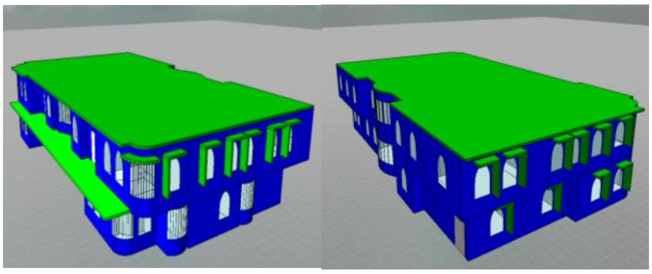

Figure 9: The south and east, north and west elevations of the building after adding shading

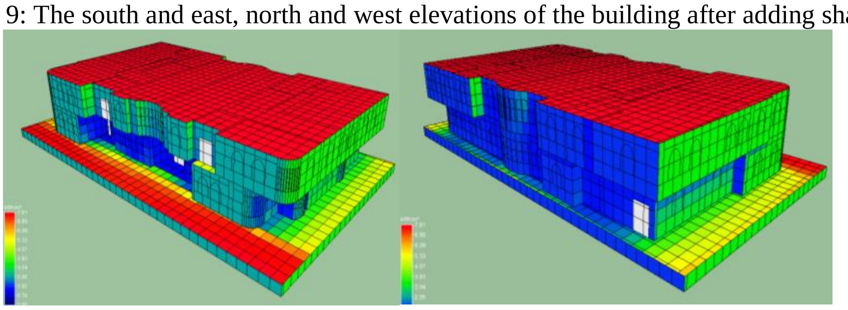

Figure 10 South and East, North and West and roof solar gain simulation result

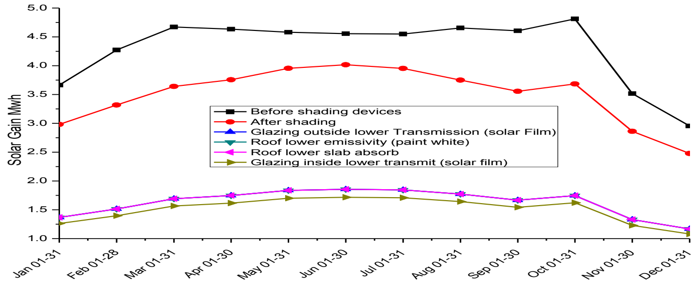

Figure 11: The building monthly solar gain.

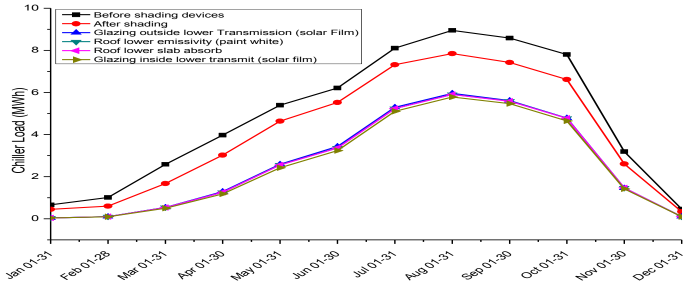

Figure 12: Building chiller loads per MWh

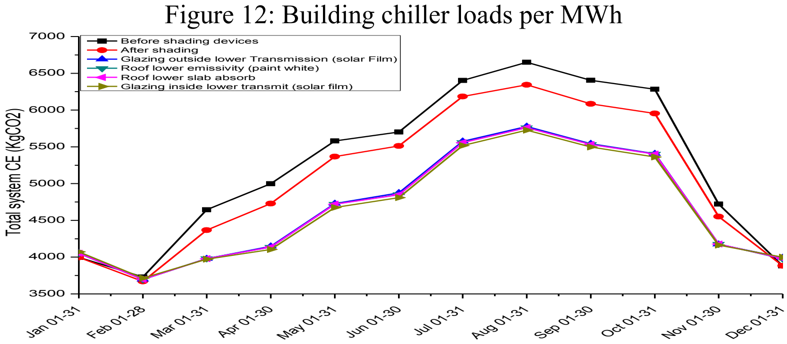

Figure 13: The total CO_2 produced by the building

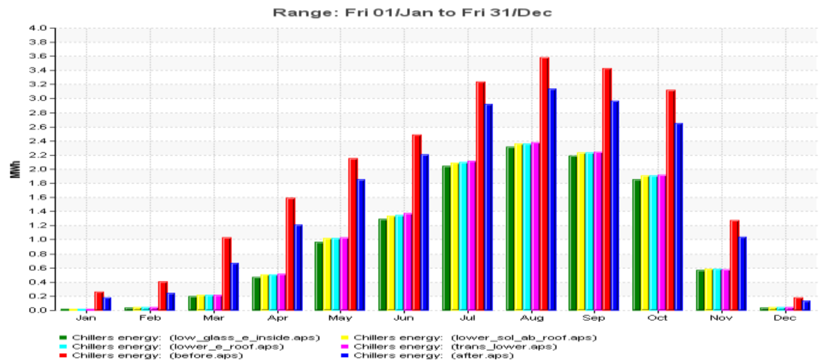

Figure 14: shows the chiller energy for the whole year

On-site measurements of thermal performance of a residential building in a hot-arid region

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The Effect of Outdoor Air Temperature on the Thermal Performance of a Residential Building

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***Abstract*—This paper gave an account on the field measurements of the outdoor air temperature on a typical residential building in Tripoli, Libya. The outdoor air temperatures were measured at two distinctive heights for 45 days.**

Sensors were located in and outside the building to record the temperature, humidity and electricity consumption from 5th July to 18th August, 2013. The temperature readings for the four facades were taken every two hours throughout the day on the walls, window glazing and the roof surfaces using infra-red cameras.

The influence of the outdoor air temperature due to the sun on the building facades was examined and compared with the walls, glazing and roof surfaces of the building. The type of building materials used, the design form adopted, orientation of the building, and the climatic period under consideration greatly influences the amount of outdoor air temperature that the building and its fabrics can absorb, store and dissipate both internally and externally.

Keywords*—*Air temperature, Climatic change, Libya, Residential building, Thermal performance.

I. INTRODUCTION

In recent times, modern architecture often adopted in most of our cities particularly in Libya, often over concentrates on aesthetics than the adoption of energy conscious designs. Modern building designers have stepped away from simple vernacular designs towards designs characterized by heavy energy consumption both in terms of their construction methodology and maintenance culture. This had led to many of such residential buildings providing poor quality indoor and outdoor environment that require huge amount of energy to run air conditioning, extractors among others [1]. This usually influences the thermal comfort and energy consumption and carbon emissions within the built environment in such regions. Due to the impact on climate change, there is a growing need for building service engineers and designers to design buildings which do not only provide comfort for the occupants but also minimize the consumption of fossil fuels and its resultant greenhouse gas emissions in the process of heating and cooling [2].

Again, most residential buildings in hot rid regions such as Libya experiences high cost of energy usage in cooling due to the predominant use of materials such as blocks which are of low thermal mass in construction and extensive use of glazing [3]. Principally, the hot and humid nature of the climate in such regions makes the climatic conditions largely fall outside the human comfort zone which in most cases demands cooling with air conditioners. The construction of most residential buildings in Libya often employs bricks of high thermal mass value. This is contrary to other countries in the tropics where sandcrete blocks of low thermal mass are mostly used [3]. Also, the current movement and choice of glazing as an element for wall cladding and windows without regards to local climatic conditions has often increase the thermal energy consumption both in and outside the building.

Moreover, there is little research on the thermal performance of buildings arising out of the use of these materials in relation to the effect of the outdoor air temperatures dynamics on the building in this part of our world. The aim of this paper is to explore the effect of the outdoor temperature on the thermal performance of a typical residential building located in Tripoli in Libya.

II. THERMAL CHARACTERISTICS OF RESIDENTIAL BUILDINGS IN HOT ARID REGIONS

Building designs and user characteristics

A residential building can be made more energy efficient basically by relating its facades to the sun and outdoor air movement. Furthermore, spaces that require cooling very often need to be located on the northern facades. A building that outstretched along its east-west axis would have its longer south facades subjected to the highest heat gain during winter and its shorter east and west elevations to a maximum heat gain in summer time. Consequently, a building that elongates along that direction is considered to be the largely efficient shape in all climates for minimizing the heating requirements in winter and cooling in summer [4]. In addition, the

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Exploring the Energy Consumption Dimensions of a Residential Building in Tripoli, Libya

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***Abstract*— A huge numbers of recently-built residential buildings in Libya provide a poor quality indoor environment which requires a large amount of energy to provide not only comfortable indoor environment but run the air conditioning. Also, the use of energy in buildings is becoming a major contributor to both air pollution and climate change. Improving the energy efficiency, reducing the energy consumption, securing thermal comfort in residential buildings through the application of bioclimatic design principles is a very critical factor. A domestic building in Libya was studied with a view of reducing its energy consumption. The study included detailed monitoring which was followed by a computer simulation with a wider range of intervention strategies. The use of appropriate orientation, materials and building configuration which would offer suitable solutions to the energy and environmental problems in hot arid countries are recommended.**

Keywords*— *Architectural design, climatic change, Energy in building, Libya, Residential buildings

I. INTRODUCTION

A huge number of recently-built residential buildings in Libya provide a poor quality indoor environment which requires a large amount of energy to provide not only comfortable indoor environment but run the air conditioning [1]. Also, the use of energy in buildings is becoming a major contributor to both air pollution and climate change. Reference [2] reports that the contribution of buildings alone towards the global energy consumption, is in the range of between 20% and 40% in developed countries which made the built environment a major contributor than industrial and transportation sectors. Improving the energy efficiency, reducing the energy consumption, securing thermal comfort in residential buildings through the application of bioclimatic design principles is a very critical factor which needs consideration.

Also the energy use for air conditioning in hot climates regions such as Libya is one of the significant contributors to fossil fuel depletion and carbon emissions [1][6][7]. In particular, air conditioning in residential buildings constitutes a substantial proportion of building energy use due to the long occupancy hours. Reference [3.p201] report that, urban areas particularly in developing economies without high climatic quality use more energy for air conditioning and lighting in summer periods. Typically, the cooling environment provided at any particular time does not precisely match the cooling load at that time as the air condition units do not have a continuously variable output. Moreover, the occupancy patterns are not continuous and the on and off witching of the air condition units whenever the room is occupy or vacated, allows the heat gains to build up over a period. In this paper, the temperatures and energy consumption in a multi-occupancy building in Libya were monitored over an extended period of 45 days to characterize the energy consumption patterns in relation to the climate and occupancy. Besides, the issue of discomfort and inconvenience arising out other urban activities, high temperatures, wind tunnel effects, erroneously and insufficient designed of residential buildings is very common [4].

Available statistics on the electricity consumption among some European cities ranges from 60 GWh to 26,452 GWh per annum [3]. Moreover, the average electricity consumption calculated on the basis of available data for cities with more than 1,000,000 inhabitants is around 4500 GWh per annum [3]. The above according to [2] has also raised concerns over supply difficulties, exhaustion of energy resources and heavy environmental impacts on residence and the building fabrics particularly in developing economies such as Libya. The city of Tripoli lies on the far north of the continent of Africa overlooking the Mediterranean Sea. The ordinates of the city are latitude 32° 47" N and longitude 13° 04" E respectively. Tripoli is classified as a hot dry climate, which usually is found on latitudes between 20°C and 35°C.

Courses and research events the researcher has attended

1. Going for Gold - London 2012 Olympic and Paralympic Park Project 1st November 2012 IBUD Seminar led by Professor Dorte Rich Jørgensen.
2. Application of green energy systems in the built environment Dr Mohamed Abdel-Wahab IBUD seminar 28th November 2012.
3. Seminar on BIM-based Integration of Virtual and Physical Building Components on October 3rd, Wednesday Speaker: Prof. Chimay J. Anumba, Head, Department of Architectural Engineering, The Pennsylvania State University, USA.
4. Seminar on "Railway Track Transitions: Issues and Solutions" & "DART3D" Speakers: Prof. Peter Woodward (Director of IIE) & Abdellah El-Kacimi, 26th September 2012.
5. Seminar on BIM-based Integration of Virtual and Physical Building Components by Prof Chimay Anumba, 3rd October, 2012.
6. Internal IIE Graduate School Launch Event Poster Session 14th November 2012.
7. Library Workshop (develops writing skills and Referencing).
8. AutoCAD (CAD)/Revit Architecture (BIM) Open workshops Resource Centre Galley.
9. IBUD seminar with two papers from the Urban Energy Research Group Vicky Ingram – 'Green deal or green wash: A case study analysis of the Government's flagship energy efficiency policy' on 21st January 2013.
10. Seminar transformation of open spaces in Kathmandu– Place-making and place-keeping: experiences in long-term management of open space around northern Europe on 20th February 2013 Dr Harry Smith.
11. Sustainable Development: Infrastructure Challenges and Solutions conference on the 26th February 2013 at Heriot- Watt University.
12. IBUD seminar two speakers: Ali Agha – 'Energy consumption in the textile industry and Professor Ming Sun – Construction project changes: causes, effects and management tools Wednesday 6th March 2013.
13. ICARB's 5th International Conference on Carbon Accounting, 13th March2013 Edinburgh, Heriot-Watt University.

14. "pink pound" and the "gaybourhood" – neighbourhood deprivation and sexual orientation in Scotland IBUD seminar two speakers Dr Kirsten Besemer – The Dr Peter Matthews – Planning the Digital City Wednesday 20th March 2013.
15. Seminar the Physics of Natural Ventilation: Wind Towers to Football Stadiums. By Dr Ben Hughes from the University of Leeds, Friday 22nd March 2013.
16. Inaugural Lecture, terawatt challenge and solar technologies: A journey from micro to nano-electronics by Professor Hari Upadhyaya, chair in renewable energy on Wednesday 27th March 2013.
17. Overheating workshop, by Norbert Lechner, at Heriot-Watt University held on 20th May 2013.
18. Attend exhibition ecobuild held on ExCel London 4th-6th March 2014.
19. The 8th Windsor International Conference 2014, counting the cost of comfort in changing world held 10th - 13th April 2014 at Cumberland Lodge, Windsor Green Park.
20. Attend exhibition ecobuild held on ExCel London 3rd -5th March 2015.
21. Sustainability in the Built Environment, PGR Student Research Event, Showcasing PGR student research through fast-pace Pecha Kucha presentations & research posters 18th March 2015.
22. Sustainability and Buildings walking the tightrope to 2050, Loughborough University Design School, Participate with poster on 22nd April 2015.
23. The 7th International Conference of SuDBE2015, Reading, UK; 27th-29th July, 2015, Participate with paper "Thermal Performance Measurements of a Residential Building Located in Hot Arid Area (Tripoli-Libya)".
24. Learning Enhancement and Development Skills training course (LEADS 1).

    Session 1: Introductory Lecture 29th September 2015.

    Session 2: Planning a Session and Encouraging Student Engagement (EGIS): 30th September 2015.

    Session 3: Managing Learning in Intercultural Contexts (EGIS): 6th October 2015.

    Session 3: Managing Learning in Intercultural Contexts (pre session workshop.

    Session 4: Managing Learning of Students with Disabilities: 14th October 2015.

    Session 5: Assessing Student Learning and Evaluating Teaching (EGIS): 21st October 2015.

    Session 6: Preparing for Assignment: 28th October 2015.

Session 7: for EGIS: How Students are assessed in the Department (SBE and IPE): 28th October 2015.

Session 8: Elective Pathways - Teaching in a Laboratory: 4th November 2015.

25. Learning Enhancement and Development Skills training course (LEADS 2).

Session 9: Seminar and Workshop: 2nd December 2015.

Session 10: Microteaching: 9th December 2015.